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NAS CR-145122
December 1976

PRELIMINARY EXPERIMENT
DEFINITION FOR VIDEO LANDMARK
ACQUISITION AND TRACKING

By: Roger T. Schappell, John C. Tietz,
Roland L. Hulstrom, Robert A. Cunningham
and Gwynn M. Reel

(NASA-CR-145122) A PRELIMINARY EXPERIMENT
DEFINITION FOR VIDEO LANDMARK ACQUISITION
AND TRACKING (Martin Marietta Corp.) 83 p
HC A05/MF A01 CSCI 05B

N77-19565

Unclas
21627

G3/43

Prepared under Contract No. NAS1-14489 by

MARTIN MARIETTA CORPORATION
DENVER DIVISION
Denver, Colorado 80201

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



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FOREWORD

This report presents results of a six-month video landmark acquisition and tracking study applicable to future global monitoring systems. Experiment objectives are discussed which culminated in a preliminary design of an acquisition and tracking system with several unique options. The applicable technology resulted from NAS1-13558, Video Guidance, Landing, and Imaging Systems for Space Missions and from numerous internal area correlation development programs.

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PRELIMINARY EXPERIMENT
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By: Rober T. Schappell, John C. Tietz, Roland L. Hulstrom,
Robert A. Cunningham and Gwynn M. Reel

INTRODUCTION

We are into an era where global monitoring systems are carrying instrumentation capable of providing much useful information essential to environmental monitoring, remote sensing of land resources, meteorological data, navigation, and gravimetric geodesy. Future missions are currently being planned that will significantly extend these capabilities based on the Space Shuttle payload capabilities, new and enhanced sensor response, improved image enhancement techniques, and high-speed tape recorders. The fact of the matter is that these improved data gathering techniques will result in voluminous information requiring unreasonable amounts of time and manpower for eventual reduction before final distribution to the user can occur. It is for this reason that video landmark acquisition and tracking techniques are being investigated with the primary objective of providing a means for acquiring and tracking the landmark or constituent of interest, providing pointing coordinates for the science sensors, and negating data acquisition during periods when there are no science observables. This will in turn enhance the end-to-end data management program by significantly reducing the quantity of raw data acquisition. In other words, this study is concerned with the development of an adaptive, real-time search, acquisition, and tracking system capable of operating in an autonomous mode with the ability to be re-programmed to acquire certain generic type features and/or specific landmarks.

The approach taken in the development of this technology is as follows:

- Define a representative set of experiment objectives;
- Evaluate uniqueness; i.e., spectral response and physical characteristics, of selected reference targets;
- Consider impact of spacecraft and mission criteria;
- Perform preliminary design of sensor system and discuss available options.

During the course of the performance of this study, a broad spectrum of recognition, acquisition, and tracking techniques were considered. It included very fundamental edge

detection algorithms as well as the more complex pattern recognition techniques. Area correlation techniques have also been extensively studied with respect to the intended application.

It soon became apparent that if one is to arrive at an operational recognition, acquisition, and tracking system within the time frame of Shuttle, more fundamental algorithms must be considered with truly adaptive characteristics with regard to the target(s) or constituent of interest. Furthermore, for certain specific targets an area correlation capability will be useful. With regard to the latter, the required area correlation technology is available due to a number of military programs and can be readily applied to NASA type global monitoring programs.

This report is organized to provide the reader with a basic knowledge of the candidate concepts as well as a preliminary design of the reference configuration. The Summary chapter discusses the experiment objectives, the reference configuration, and the potential modes of operation. The Experiment Objectives and Target Definition chapter provides a rationale for having selected specific generic type surface features as targets for the reference configuration. The chapter on Candidate Concepts provides a tutorial discussion on how the various recognition, acquisition, and tracking concepts function. The Preliminary Selection Results and System Designs chapter provides the essential weight, power, and configuration data and establishes the necessary detail for the next phase of study. The conclusions chapter summarizes the study results and is followed by the pertinent references.

SUMMARY

Six scientific objectives/experiments were derived which consisted of Agriculture/Forestry/Range Resources, Land Use, Geology/Mineral Resources, Water Resources, Marine Resources and Environmental Surveys. Computer calculations were then made of the spectral radiance signature of each of twenty-five candidate targets from 0.4 to 0.90 micrometers as seen by a satellite sensor system. Further inspection of these signatures, previously reported research, and laboratory experiments (ref. 1) indicated that a potentially useful technique for automatic recognition and acquisition of a target for pointing and tracking would involve the definition of the spectral bands that best characterizes the target. Band pairs with a radiance that best distinguishes the target of interest from other scenes with similar spectral content were selected. This ratio was computed for each target with very positive results.

As a result of the spectral radiance study for target identification, a water pollution imager experiment with cloud detection capability was selected to be used as the basis for further sensor system design. This, in turn, required further refinement of the water-way tracking algorithm and applicable hardware.

This study has resulted in the definition of an imaging system capable of recognizing, acquiring and tracking specific generic type surface features. Additional functions such as area correlation of a prestored area can be accomplished but are not part of the baseline design. Since it was the intent of this study to perform a preliminary experiment definition and design of a Video Landmark Acquisition and Tracking (VILAT) system based on work performed under NAS1-13558, "Video Guidance, Landing, and Imaging Systems for Space Missions," a baseline system having the following features was selected:

- | | |
|---------------------|---------------------------------------|
| ● System Weight | - 7 kg (15 lb) |
| ● Power | - 28 watts |
| ● Volume | - 6000 cm ³ |
| ● Field of View | - 2.2 deg (function of optics design) |
| ● Pointing Accuracy | - 60 sec (function of optics design) |

This device will search a 10-mile swath while orbiting the earth, looking for land/water interfaces such as coastlines and rivers. While in the "track" mode, it will provide servo error signals and an enabling logic command to point relevant science sensor(s) at the acquired surface feature and then negate data acquisition upon having lost lock due to the science observable having left the field of view or due to obscuration by clouds of the acquisition and tracking system. The analog outputs from the reference VILAT system are sampled data, processed through a zero order hold and have an update rate of 1600 samples per second. The tracking rate can be adjusted to accommodate a wide range of servo bandwidths and slewing rates.

Although not part of the baseline design, correlation logic can be added which would use the same sensor and optics with a resultant increase in weight, power, and cost. This correlation algorithm has been developed and tested in the laboratory.

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EXPERIMENT OBJECTIVES & TARGET DEFINITION

The rationale for development of the Video Landmark Acquisition and Tracking System (VILAT) is apparent when one considers the various earth observation missions currently under consideration by the Earth Viewing Application Laboratory (EVAL) discipline working groups and other organizations within NASA. Unfortunately, much of the experiment definition is presently in progress and not yet firmly established. Nevertheless, this chapter includes a discussion of several of the applicable experiments, a brief description of the potential Shuttle flight test vehicle, and a dissertation on target spectral content.

Experiment Objectives

Specific earth observation missions will dictate stringent pointing and stability requirements for each science sensor in order to accomplish its associated mission. Furthermore, it is evident that a number of the same experiments will benefit when the target or constituent of interest can be identified and tracked via the use of an auxiliary sensor. Tabulations of pointing and stability requirements (ref. 2) for several candidate sensors indicated in Table I have been assembled and are summarized in Table II. These pointing and stability requirements were established by considering the selected sensor characteristics and the observation/coverage requirements of the designated mission. The pointing accuracy relates the relative location of area viewed by the sensor with respect to the desired coverage area. The pointing stability error amplitude is the amount of temporal variation of the sensor line of sight (LOS) from the desired LOS less the pointing error during the viewing period. The pointing stability error rate is the average time derivative (slope) of the variation over a period as shown in Figure 1.

Although it was recognized by the investigators of the study summarized in reference 2, that different limit values would be required for pitch, roll and yaw axes, for simplicity, only one limit value for each sensor was established.

The pointing accuracy was established primarily from the field of view of the sensor and the size of coverage area. As shown in Figure 2, the limit values range from 10 arc seconds for LIDAR to 1800 arc seconds (0.5 degrees) for the earth resources mission sensors. It indicates that a pointing

TABLE I.- SENSOR GROUPINGS PER MISSION

MISSION	SENSORS
EARTH RESOURCES	
Mineral Exploration Survey	<ul style="list-style-type: none"> • Thematic Mapper • Large Format Camera • Synthetic Aperture Radar (SAR)
Timber Volume Inventory	<ul style="list-style-type: none"> • Thematic Mapper • Earth Terrain Camera (S-190B)
U. S. Census	<ul style="list-style-type: none"> • Multispectral Camera (S-190B) • Earth Terrain Camera (S-190B) • Optical Bar Panoramic Camera (S-163) • Thematic
ENVIRONMENTAL QUALITY/WEATHER AND CLIMATE	
Urban Air Pollution	<ul style="list-style-type: none"> • Measurement of Air Pollution Species (MAPS) • Correlation Interferometer Meas. of Trace (CIMATS) • Temperature/Humidity IR Radiometer (THIR)
Tropospheric/Stratospheric Pollution	<ul style="list-style-type: none"> • Lower Atmospheric Composition and Temperature Experiment (LACATE) • Solar Backscatter UV and Total Ozone Mapping Spectrometer (SBUV/TOMS)
EARTH AND OCEAN PHYSICS	
Tropical Storm Research	<ul style="list-style-type: none"> • Altimeter • Synthetic Aperture Radar (SAR) • Scanning Multichannel Microwave Radiometer (SMMR) • Scatterometer • Visual and IR Radiometer (VIRR)
COMM/NAV	
EEE	<ul style="list-style-type: none"> • Electromagnetic Environment Experiment (EEE)
AMBA (Adaptive Multibeam Antenna)	<ul style="list-style-type: none"> • Adaptive Multibeam Phased Array (AMPA)
TECHNIQUE DEVELOPMENT	
Soil Moisture	<ul style="list-style-type: none"> • Thematic Mapper • Imaging Radar • Shuttle Imaging Microwave System (SIMS) • Polarimeter
TECHNOLOGY SENSOR DEVELOPMENT	
LIDAR	<ul style="list-style-type: none"> • LIDAR

TABLE II.- PRELIMINARY INSTRUMENT POINTING/
STABILIZATION REQUIREMENTS SUMMARY

Pointing Accuracy	10 $\widehat{\text{sec}}$ to 1800 $\widehat{\text{sec}}$
Pointing Stability Error Amplitude	0.2 $\widehat{\text{sec}}$ to 360 $\widehat{\text{sec}}$
Pointing Stability Error Rate	2 $\widehat{\text{sec}}/\text{sec}$ to 360 $\widehat{\text{sec}}/\text{sec}$
Duration of Stabilization	10 millisec to 30 minutes
Slew Angle	± 25 degrees
Settling Time	2 seconds (Max)
Maximum Acceleration	0.1 radians/sec ²
Maximum Slew Rate	0.1 radians/sec
Mass	9 kg to 1500 kg (per instrument) 97 kg to 2407 kg (per mission)

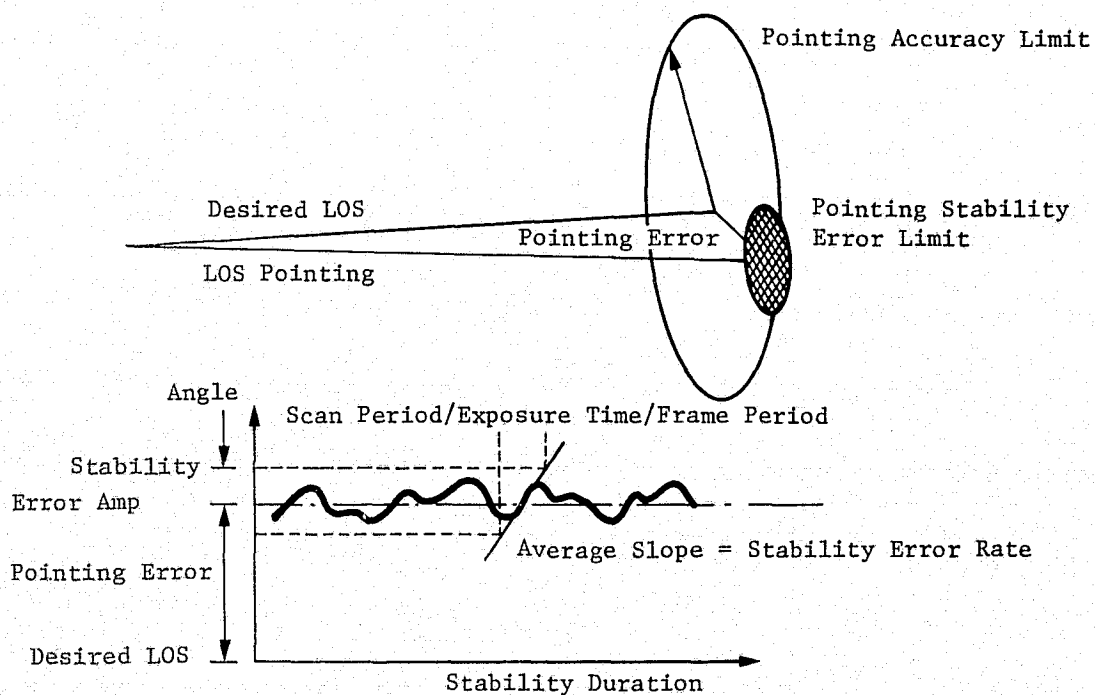


Figure 1.- Pointing Stability Error Rate

capability of 0.05 degree can satisfy most of the sensor pointing requirements while 0.5 degree accuracy provided by the on-board navigation system meets the requirements of the earth resources mission sensors only.

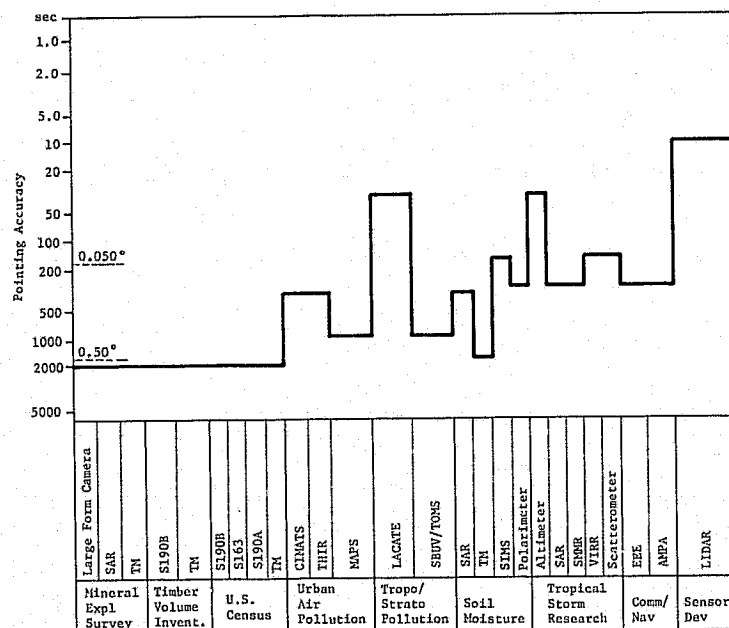


Figure 2.- Missions/Sensors Pointing Accuracy

The limit value of pointing stability error amplitude was obtained from the sensor spatial resolution since it relates to the overlapping of resolution cells. The limit values range from 0.2 arc second for LIDAR to 360 arc seconds (0.1 deg) for MAPS. It indicates that a stability error of less than 6 arc seconds satisfies most of the requirements.

A comparison of the experiment stability requirements indicates that the earth observation experiments demand relatively low stability since the duration of viewing and the time available between the successive target area pointings for the earth observation experiments are very short compared to other experiments; however, the earth observation experiments do require fast slewings with short settling times.

Space Shuttle mission models for the future include earth target tracking experiments such as those previously discussed which cannot be satisfied by the basic Shuttle systems. As a result, a number of pointing systems are being developed and evaluated by NASA that will provide pointing and stability capabilities several orders of magnitude better than that achievable by Shuttle. Examples of the auxiliary payload pointing systems are as follows:

- Annular Suspension and Pointing System (ASP)
- Miniaturized Pointing Mount System (MPM)
- Instrument Pointing System (IPS)
- Small Instrument Pointing System (SIPS)

A coordinated activity with JPL and various NASA centers with regard to the application of VILAT for earth observation has been initiated and promises to provide increased Experiment Pointing Mount utility.

Shuttle Orbital Flight Test Opportunity

The prime opportunity for evaluating the VILAT system is onboard Shuttle during the Orbital Flight Test (OFT) program as part of the Flight Test Instrumentation Payload. This equipment would be mounted on an experiment pointing mount on the Shuttle Development Flight Instrumentation (DFI) pallet in the payload bay.

OFT-2 was chosen as a representative mission for VILAT evaluation and is further detailed in order to provide the reader with mission parameters and constraints.

VILAT will be useful in exploiting the unique capabilities of Space Shuttle with regard to remote sensing of land resources, environmental quality, ocean conditions, etc as per the OFT-2 applications objectives. OFT-2 is scheduled to be launched on July, 1979 with a mission flight time of up to five days and a crew of two. Orbital altitude is 90-150 n. mi. with an inclination of 32 to 40 degrees. A summary of OFT-2 mission objectives and vehicle constraints as provided by NASA is as follows:

SPACE SHUTTLE OFT-2

MAJOR FLIGHT OBJECTIVES

- To demonstrate the capability for increased launch loads.
- To demonstrate entry capability with increased payloads.
- To perform orbital thermal test.

REQUIRED PAYLOAD FUNCTION

- Provide mass for increased launch and entry weight.
- Provide mass for center of gravity.

FLIGHT PROFILE

Launch

- Inclination 30 to 40°
- Payload weight 9080 kg
 - DFI & IECM 4540 kg
 - Other 4540 kg
- Altitude 167 to 278 km
- Center of Gravity (fore/aft) 27.35m to 28.17m

On-Orbit

- Crew size 2 men
- Duration Up to 5 days
- Attitude
 - 96 hr +Z-LV, Y-POP, Low β (0 to 45°)
 - Thermal attitudes may vary no more than $\pm 5^\circ$ in any axis
 - Thermal testing will begin on day 2 and end by day 5.
 - Thermal conditioning should be planned for 10 hours before test attitudes. Actual requirements will be identified as mission planning matures.
 - Thermal conditioning is required for up to 12 hours prior to entry to satisfy TPS and structural requirements (except for contingency entry).

SPACE SHUTTLE OFT-2 - (Continued)

- Changes in controllable electrical loads shall be minimized during thermal test periods.
- Payload related activities shall be limited to preclude changes to Orbiter environment during test periods. Allowable activities will be defined on an individual payload and flight basis.

Entry/Landing

- Payload Weight 9080 kg
 DFI & IECM 4540 kg
 Other 4540 kg
- Center of gravity
 fore/aft 28.0m
 lateral -
- Cross range 1100 km
- Planned landing site EAFB

Payload related FTRs assigned to this flight are as follows:

PAYLOAD RELATED FTRs FOR OFT-2

FTR No.	FTR TITLE	COMMENTS
06VV018	Payload Bay Thermal Interaction	Data Only
54VV011	Contamination Monitoring	Continuing Test
54VV019	Payload Bay Environmental Testing	Data Only
72VV002	Data Processing Performance	Continuing Test

PAYLOAD RELATED CONSTRAINTS AND GUIDELINES

General

- No payload requiring EVA shall be planned for this flight.
- On-orbit operations shall not exceed TBD hours.

SPACE SHUTTLE OFT-2 - (Continued)

PAYLOAD RELATED CONSTRAINTS AND GUIDELINES - (Continued)

Power

- In-orbit payload power provided by the Orbiter at any given time will not exceed 1.5 kW maximum.

Remote Manipulator System (RMS)

- The RMS will not be installed for this flight; therefore, payload deployment or handling will not be planned.

Communications and Data Services

Orbiter communications and data equipment available for Shuttle operational requirements and payload support combined are:

- S-band direct PM (pulse modulated) transmitter receiver.
- S-band direct FM (frequency modulated) transmitter.
- Mission Station (MS) recorder.

Data uplink and downlink will be limited to passes over the Ground Space Tracking and Data Network (GSTDN) stations.

S-Band Direct PM Transmitter/Receiver

The S-band direct PM system is dedicated to Orbiter operational instrumentation (OI) data and provides the capability to uplink 72 kbps of data (64 kbps voice and 8 kbps cmd) and to downlink 192 kbps of data (64 kbps voice and 128 kbps TLM). Limited mission critical payload data could be put into the OI link provided the payload was compatible with the Orbiter MDM system. Present planning to meet the Orbiter FTRs may require the total pass time over a GSTDM station; therefore, there is no planned use of the PM system to downlink payload data. It may be possible to uplink limited payload data through the PM system providing the payload command input is compatible with the Orbiter MDM command data system.

SPACE SHUTTLE OFT-2 - (Concluded)

S-Band Direct FM Transmitter

The S-band FM transmitter can be used to downlink the recorded dump data, Shuttle main engine (SSME) data, TV data, analog data, and delayed or real-time payload data on a shared basis. To meet the Orbiter's FTRs, the operations data, which is prime, requires the full use of this link and the quantity of data to be downlinked will require the total pass time over each GSTDN station; therefore, there is no planned use of the FM system for downlinking of payload data.

Mission Station PCM Recorder

The Mission Station PCM recorder will be available for recording payload data. The characteristics and capability of the recorder are defined in Section 4.2.12 of the Space Shuttle Systems Payload Accommodations, Vol. XIV, JSC 07700. The S-band FM transmitter which would normally be used to dump data from the recorder is used full time for downlink of OI data; therefore, there is no planned dump for the recorder and recording time is limited. Recorders other than the MS recorder required for payload data must be provided by the payloads.

There are several other OFT flight evaluation opportunities; however, OFT-2 is discussed since the NASA Announcement of Opportunity, September 10, 1976, for the Space Shuttle Orbital Flight Test Missions describes the OFT-2 as being oriented towards earth viewing missions.

Therefore, the requirements summarized in the Experiment Objectives section of this chapter in Table II provided a reference point for VILAT system design. The Shuttle OFT missions will provide an opportunity for flight testing the instrumentation. Although OFT-2 was discussed in detail, it may prove to be more suitable to fly on a later OFT mission due to the availability or nonavailability of an experiment pointing mount. An alternative in the absence of an experiment pointing mount is to hardmount VILAT and to fly it as an independent experiment whereupon the pointing and tracking sensor would also be used in a conventional raster scan mode as a science sensor for establishing concept feasibility.

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Target Definition

This task was concerned primarily with the definition of functional requirements for the sensor system. Emphasis was placed on the functional requirements of spectral range and spectral radiance target signatures. In order to determine these requirements, various candidate scientific experiments/objectives were reviewed in terms of ground targets. Once typical ground targets were selected, computer calculations of spectral radiance signatures, for the ground targets, were performed. These results established typical values for the spectral radiance that would be viewed by the sensor system, the significant spectral bands, and the feasibility of landmark (target) acquisition and tracking.

A literature survey was conducted to define experiment objectives and candidate ground targets. The literature consisted mainly of the numerous NASA publications concerning the LANDSAT and Skylab Earth Resource science objectives and experiments such as those shown in references 3 and 4. From such literature the following scientific objectives/experiments were derived.

- Agriculture/Forestry/Range Resources
- Land Use
- Geology/Mineral Resources
- Water Resources
- Marine Resources
- Environmental Surveys

For each of the above listed scientific objectives/experiments, specific representative candidate targets were selected. This set of targets by no means includes all possible targets for each scientific objective/experiment; rather, they represent typical targets and the range of targets that would be expected for each objective/experiment. Once the representative targets were selected, they were then defined in terms of a category, with each category containing several candidate targets. These results are listed below:

<u>Category</u>	<u>Targets</u>
1. Crops	1. Alfalfa
	2. Corn
	3. Wheat

<u>Category</u>	<u>Targets</u>
2. General Vegetation	4. High Reflectance 5. Mean Reflectance 6. Low Reflectance
3. Ground	7. Limestone 8. Bare Areas (sands, desert, etc) 9. Black Earth 10. Granite 11. Gray Plowed Soil 12. Desert Terrain
4. Water	13. Snow 14. Clear Water 15. Muddy River
5. Forests	16. Autumn Forests 17. Deciduous Summer Forests 18. Coniferous Summer Forests 19. Coniferous Winter Forests 20. Deciduous Winter Trees
6. Cultural (Land Use)	21. Asphalt Road 22. Concrete Road 23. Paved Road 24. Earth Road 25. Buildings

For the targets above, reflectivities were obtained from reference 5 and are listed in Table III. The target reflectivity data were obtained from work done in the USSR (ref. 6), and the Air Force Target Signatures Data Bank established at Wright-Patterson Air Force Base, Ohio. Additional target reflectivity data were obtained from the work summarized in references 7 through 12.

For each target, computer calculations were performed to define the spectral radiance signature of the target, as viewed by the sensor system from a satellite platform. The target radiance at the satellite sensor, N_s , is given by:

$$N_s = \frac{\rho_t H T}{\pi} + N_p \quad (1)$$

TABLE III.- TARGET REFLECTANCE IN 21 SPECTRAL BANDS

		Spectral Band, microns																				
		.400	.425	.450	.475	.500	.525	.550	.575	.600	.625	.650	.675	.700	.725	.750	.775	.800	.825	.850	.875	.900
Target	1	0.39	.060	.070	.072	.089	.131	.171	.207	.230	.271	.291	.410	.540	.709	.749	.770	.782	.790	.795	.795	.790
	2	.050	.056	.069	.080	.088	.126	.150	.133	.125	.112	.100	.111	.211	.339	.505	.585	.626	.628	.630	.635	.645
	3	.012	.019	.022	.030	.035	.062	.097	.085	.055	.045	.030	.027	.073	.167	.269	.328	.359	.418	.489	.489	.489
	4	.181	.200	.226	.230	.241	.330	.350	.320	.371	.426	.429	.343	.489	.690	.718	.741	.752	.760	.766	.767	.766
	5	.049	.060	.070	.078	.080	.145	.158	.130	.120	.110	.099	.082	.280	.402	.480	.529	.530	.531	.532	.539	.548
	6	.019	.020	.020	.021	.021	.030	.041	.037	.031	.028	.021	.020	.049	.189	.200	.241	.265	.270	.275	.275	.275
	7	.357	.416	.475	.522	.558	.592	.622	.645	.667	.685	.697	.707	.718	.725	.732	.739	.744	.751	.753	.753	.753
	8	.108	.128	.150	.168	.186	.207	.323	.257	.273	.280	.281	.285	.290	.297	.306	.314	.318	.333	.341	.341	.341
	9	.022	.023	.023	.025	.026	.027	.029	.030	.030	.034	.036	.039	.041	.044	.046	.050	.059	.067	.071	.071	.071
	10	.120	.138	.155	.179	.195	.206	.235	.260	.270	.278	.281	.287	.292	.301	.310	.315	.319	.321	.339	.342	.349
	11	.031	.040	.035	.032	.040	.050	.051	.055	.060	.057	.059	.070	.075	.086	.132	.210	.229	.227	.221	.221	.221
	12	.105	.135	.175	.185	.197	.231	.250	.248	.245	.240	.230	.222	.267	.360	.510	.559	.565	.575	.571	.572	.571
	13	.830	.824	.820	.808	.798	.788	.775	.768	.756	.747	.735	.723	.710	.698	.685	.673	.655	.637	.630	.630	.630
	14	.125	.110	.100	.084	.072	.058	.048	.039	.035	.029	.024	.018	.013	.011	.010	.010	.010	.010	.010	.010	.010
	15	.150	.160	.170	.182	.196	.200	.206	.205	.200	.195	.179	.165	.152	.147	.121	.112	.091	.079	.065	.060	.060
	16	.051	.058	.062	.073	.083	.123	.168	.192	.196	.193	.193	.237	.315	.394	.460	.509	.540	.558	.564	.564	.564
	17	.039	.043	.048	.052	.060	.097	.134	.118	.101	.091	.084	.104	.176	.293	.397	.462	.516	.537	.542	.542	.542
	18	.033	.037	.041	.045	.050	.069	.088	.082	.078	.079	.077	.042	.140	.199	.239	.275	.284	.292	.305	.305	.305
	19	.070	.082	.090	.092	.099	.108	.120	.120	.120	.121	.158	.175	.206	.235	.240	.249	.253	.258	.258	.258	.258
	20	.120	.120	.121	.128	.140	.140	.140	.140	.150	.158	.170	.188	.200	.230	.260	.292	.332	.335	.335	.335	.335
	21	.10	.10	.105	.12	.13	.13	.12	.13	.14	.14	.145	.15	.165	.18	.18	.175	.16	.15	.15	.155	.16
	22	.25	.26	.26	.26	.255	.276	.30	.32	.33	.335	.36	.40	.445	.44	.35	.30	.29	.26	.24	.25	.27
	23	.064	.066	.068	.073	.077	.083	.090	.093	.098	.102	.107	.128	.165	.184	.204	.221	.224	.260	.270	.270	.270
	24	.115	.13	.142	.152	.16	.17	.195	.21	.22	.215	.208	.23	.27	.28	.285	.29	.305	.325	.325	.325	.325
	25	.064	.066	.068	.073	.077	.083	.090	.093	.098	.102	.107	.128	.165	.184	.204	.221	.244	.260	.270	.270	.270

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where ρ_t is the target reflectance, H is the total incoming solar irradiance, T is the atmospheric fractional transmittance, and N_p is the atmospheric path radiance between the sensor aperture and the target. A detailed discussion of these parameters is given in reference 13. The computer program used to calculate N_s was originally developed by NASA and ERIM (Dr. Turner), (ref. 14). The required inputs/variables to the program are listed below:

- Atmospheric Visual Range
- Solar Zenith Angle
- Solar-Sensor Azimuthal Angle
- Background Albedo
- Nadir Sensor Viewing Angle

The atmospheric visual range defines the transparency of the atmosphere. For calculations reported here, an atmospheric visual range of 23 km (at sea level) was chosen as being representative of clear conditions (as opposed to hazy conditions). The solar zenith angle is defined by the angle between the zenith and the sun. A nominal value of 30° was chosen for this study. The solar-sensor azimuthal angle is the angle between the solar vector and the direction of the sensor view. An angle of 0° was chosen for this study. This represents conditions where the target is viewed in the same vertical plane defined by the target normal (zenith) and the solar vector. Background albedo is defined as the reflectivity of the ground that surrounds the target. For the purposes of this study, the background albedo was assumed to be identical to the target reflectivity. The nadir sensor viewing angle is defined by the angle between the satellite/sensor nadir and the viewing angle. For this study, the sensor was assumed to be viewing the target at the nadir (0°).

For each of the targets listed in Table III, a spectral radiance signature was computed. Shown in Figure 3 are results for five representative targets of bare areas, wheat, muddy river water, clear water, and general (mean) vegetation. This was done for the purpose of determining the general nature of the radiance signatures; and, subsequently, determining the feasibility of automatically acquiring the targets. As shown in Figure 3, the vegetation targets (wheat and mean vegetation) display similar radiance signatures that are characterized by low radiance in the visible region (0.4 to $0.7 \mu\text{m}$), and a sharp increase in radiance toward the near infrared (0.7 to $0.9 \mu\text{m}$) region. This is due, of course, to

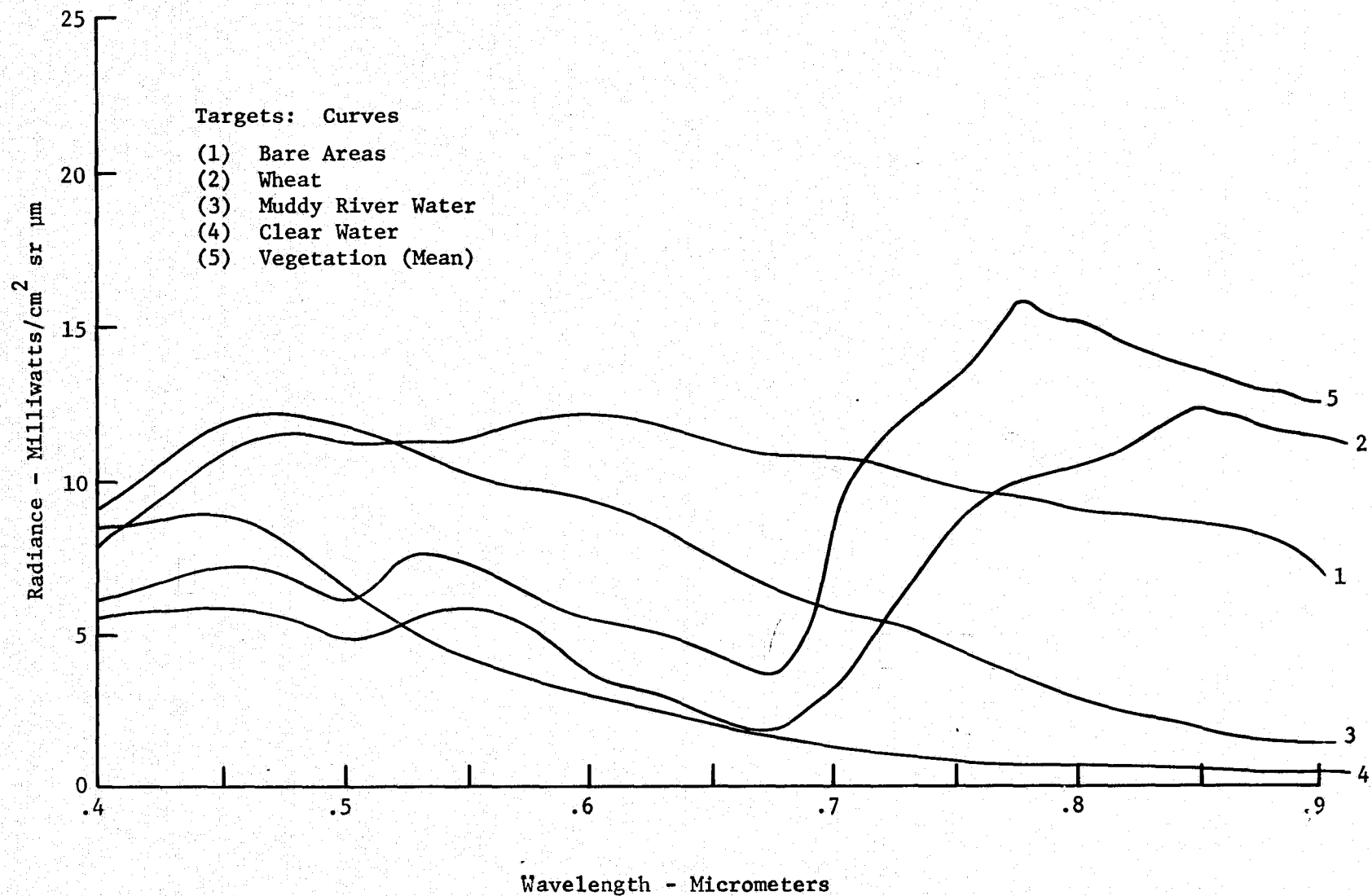


Figure 3.- Target Spectral Radiances

chlorophyll absorption at wavelengths of 0.4 to 0.5 μm , and 0.65 to 0.69 μm , and a very high reflectance of the near infrared wavelengths. These unique absorption and reflectance characteristics of green vegetation have been investigated by Miller and Pearson, (ref. 15) and Tucker, (ref. 16). They have shown that a ratio of the near infrared and chlorophyll absorption bands is well correlated with the amount of green biomass within a scene. In addition, Maxwell, (ref. 17), has employed a similar ratio for mapping green vegetation from a satellite (LANDSAT). It is also apparent that such a ratio, say the ratio of the 0.650 to 0.850 μm radiances, is also a good identifier of the water and bare areas. This is due to the fact that the water targets strongly absorb in the near infrared region while the bare area target is relatively uniform over all wavelengths. An analysis of this ratio was made for all twenty-five targets--the results are shown below:

<u>Category</u>	<u>0.65/0.85 N_s Ratio</u>
• Crops	
Alfalfa	0.575
Corn	0.294
Wheat	0.177
• Vegetation	
Green - High	0.860
Green - Mean	0.308
Green - Low	0.266
• Ground	
Limestone	1.410
Bare Areas	1.290
Black Earth	1.210
Granite	1.260
Gray Plowed Soil	0.560
Desert Terrain	0.648
• Water	
Snow	1.78
Clear Water	3.29
Muddy River Water	3.89
• Forests	
Autumn Forests	0.537
Deciduous Summer Forests	0.300
Coniferous Summer Forests	0.494

<u>Category</u>	<u>0.65/0.85 N_s Ratio</u>
• Forests - (Continued)	
Coniferous Winter Forests	1.020
Deciduous Winter Trees	0.839
• Cultural (Land Use)	
Asphalt Road	1.570
Concrete Road	2.270
Paved Road	0.709
Earth Road	1.030
Buildings	0.709

These results are graphically depicted in Figure 4, where the 0.650/0.850 radiance ratio is plotted versus the target category. It can be seen that the target categories made up of vegetation, Nos. 1, 2, and 5, have similar ratios. These vegetation ratios are characterized by values less than 1.000. The ground targets are characterized by ratios greater than one and less than two. The water targets are characterized by a very distinctive ratio of greater than three and less than four. The cultural targets do not have a distinctive ratio range.

The above analyses indicate the 0.650/0.850 ratio is indicative of water, vegetation, and ground targets; however, cultural targets are not as uniquely identified. It appears that by using the 0.650/0.850 ratio it would be feasible for a sensor system to acquire and track water, vegetation, and ground targets; and, it would be able to differentiate boundaries between these targets. This two-band ratio has the advantages of (1) improved signal to noise, (2) independent of sun angle, and (3) relatively independent of atmospheric fluctuations. (ref. 17)

It should be pointed out that the above analyses were performed with a somewhat limited set of targets; however, the two band ratio (0.650/0.850) technique exhibits promise in terms of acquiring and tracking the targets of water, vegetation, and ground. It may be possible to greatly expand the number and type of targets that can be differentiated/acquired with the two band ratio system. Such an expansion of targets will require the "training" of the sensor system. This "training" would consist of viewing known targets and measuring the 0.650/0.850 radiance ratio. Hence, the sensor system could then be "trained" to recognize unknown targets by

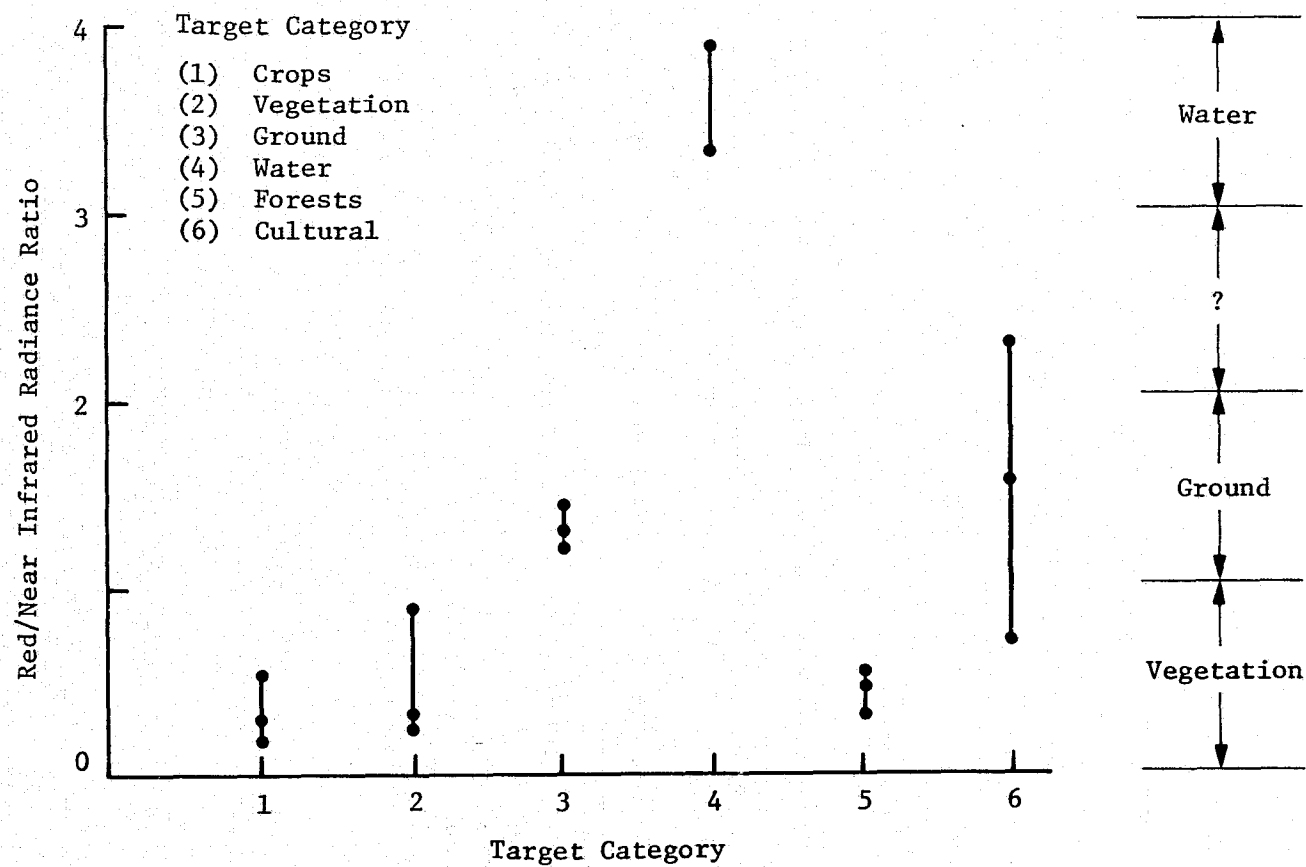


Figure 4.- Red/Near Infrared Radiance Ratio for Target Categories

comparison of the measured 0.650/0.850 radiance ratio with known values for given targets. Such "training" techniques are commonly performed by investigators using LANDSAT data to automatically map water quality, crops, forests, etc.

In summary, a total of six scientific objectives/experiments were derived. These consisted of Agriculture/Forestry/Range Resources, Land Use, Geology/Mineral Resources, Water Resources, Marine Resources, and Environmental surveys. Subsequently, a total of twenty-five candidate targets were defined for the scientific objectives/experiments. Computer calculations were made of each target's spectral radiance signature, from 0.4 to 0.90 micrometers, as seen by a satellite sensor system. Inspection of these signatures and previous research reported in literature indicated that a potentially successful technique for automatically acquiring and tracking the targets is the ratioing of the target's radiance at 0.650 μm to the radiance at 0.850 μm . For each target this ratio was computed and the results indicated that the targets displayed three distinct ratio regions. These distinct ratios were for vegetation (crops, forests, and general vegetation), water (clear, and muddy river), and ground (bare areas, geologic and crops, etc). It may be possible to acquire and track selected targets, within these general groups, by conducting "training" of the sensor system. This "training" consists of actually viewing and measuring the ratio with a sensor system either from orbit and/or high altitude aircraft. A data bank of ratios versus targets could then be established and used to subsequently acquire and track targets.

CANDIDATE CONCEPTS

A number of different targets lend themselves to tracking with a video system. The cost and complexity of such a system are, however, highly dependent on the nature of the target or targets to be tracked. Specifically, cost and complexity are a function of:

- How readily the target is distinguished from features that are not targets,
- How many different targets are to be tracked by the same system,
- How large the target is, and
- How accurately the target must be tracked.

To illustrate how these factors affect the required system complexity and cost, a number of representative tracking systems are discussed. They range from simple cloud detection schemes to the more complex color correlation systems.

For clarity, this chapter is broken down into two major sections--Generic Surface Feature Detection Concepts and Correlation Techniques. It is important to note that the functions discussed in each section can be combined in the same instrument if required by target acquisition, experiment pointing, and tracking requirements. As an example, the coast-line tracker described here could also operate in a correlation mode using prestored target data. On the other hand, the additional electronics for a given function may increase system weight and cost needlessly if there is no requirement for it.

If the primary requirement is landmark tracking via correlation with prestored targets, accuracies of better than 100 meters (328 ft) are achievable with the two CCD correlation concepts discussed at the end of this chapter. These approaches would provide autonomous operation and accuracies currently unachievable with more conventional spacecraft instrumentation. Spacecraft requiring precision data for vehicle attitude determination and/or pointing control with respect to earth targets; i.e., registration, would benefit from the application of correlation technology.

Generic Surface Feature Detection

Cloud Detector.-- A modest goal for a video system is to simply suppress image transmission from the satellite when cloud cover

exceeds a certain percentage of the total picture area. Such a system would not actually track features or produce pointing signals for other equipment but would provide the commands for activating other science instrumentation.

This can be accomplished by using analog signal processing electronics to determine the ratio(s) of the video signals for one or more spectral bands. The ratio signal is fed to a comparator, the output of which is a "1" when a cloud is observed and an "0" state otherwise. The video signal could be derived from the primary imaging sensor, if it has filters for the appropriate spectral bands. For a scanning sensor, the comparator output would gate a clock signal to a preset counter. The count at the end of each line or frame would be a direct measure of the cloud content in the picture. Such a system could also distinguish between clouds and snow if the sensor included a band around 1.7 microns, where snow appears dark.

Where this system would make use of an existing sensor, cost would be very low. The entire system could be assembled on a single circuit board.

Water/Land Boundary Detector.- With a slight increase in complexity, the system described above can be modified to observe only areas that are a certain percentage land and a certain percentage water. This would increase the number of parts required for signal processing, but cost and complexity would still be low. A diagram of such a system is shown in Figure 5.

Cloud detection capability can be incorporated into the same package. Such a system would transmit imagery of coastlines, swamps, marshes, and so forth while suppressing such imagery when cloud cover is excessive.

The systems described above are referred to as color ratio detectors. Although such systems tend to be simple (and therefore relatively low in cost), they are limited in capability. A land/water boundary detector would be equally responsive to, for example, the west coast and the east coast of the United States. Nor could it provide good pointing information for a camera or experiment if it came close to a coastline but was not centered on it. Its output is simply a yes/no decision.

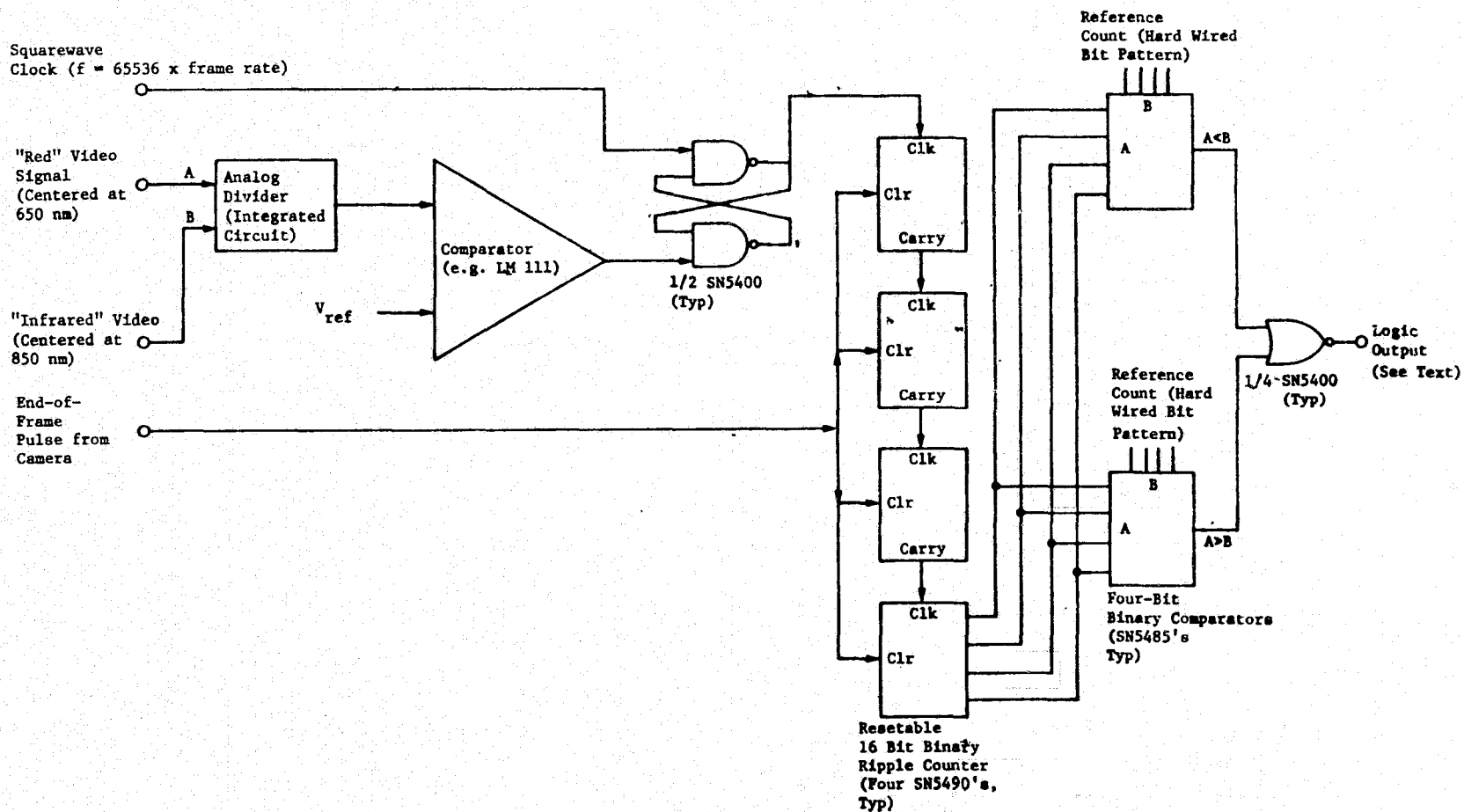


Figure 5.- Water/Land Boundary Detector

This approach can be applied to targets other than water and clouds. For example, it could be used to find a particular type of vegetation. However, few targets have a very distinct spectral signature. Such a system would, therefore, be prone to make mistakes, and adding spectral bands to improve performance would tend to increase the cost. Also, some targets' spectral signatures are mimicked by mixed terrain, while other targets change with the seasons. Such a system is, therefore, not recommended for targets with a variable or indistinct spectral signature or for targets whose spectral signatures are mimicked by common blends of signatures unless a fairly high error rate can be tolerated. The error rate might be reduced by having an input command turn the system on only when the satellite is near the target.

Almost any imaging sensor can be used for a system of this type. CCD and CID sensors, due to their attractive weight, power requirement, spectral response and ease of scan implementation, would be prime candidate sensors.

Coastline/River Tracker.- A somewhat more complicated task is to track a coastline until a river is encountered, then track the river until it becomes obscured by clouds or becomes too small to track. Such a system would produce pointing signals to aim a high-resolution camera and would be useful in a study of marine environments. The object is to give a factor of 20 improvement in pointing accuracy for the primary sensor, which uses a camera similar in quality to the one in the tracker, but with a lens of much longer focal length. It is assumed that all rivers are equally of interest but that a sequence of pictures is desired, tracking the polluted waters upstream from a river's mouth.

Time is a primary constraint on this type system. For example, if the system were required to track rivers as narrow as 244 m (800 feet) from a satellite having an altitude above the target of 418 km (260 miles) and an orbital period of 97 minutes, this river will flash past a point on the camera's focal plane in about:

$$800 \text{ ft} \times \frac{97 \text{ minutes}}{25000 \text{ miles}} \times \frac{1 \text{ mile}}{5280 \text{ ft}} \times \frac{60 \text{ sec}}{1 \text{ minute}} \times \frac{1000 \text{ millisec}}{\text{sec}} =$$

35 msec

This allows only about 1/30 of a second to find the river and

derive enough information to point the high-resolution camera and predict where the system should look for the river as it scans a second time. (The latter is required to make the system track the river, as opposed to performing the simpler task of merely photographing rivers in general.) This time is too short for sophisticated pattern recognition techniques, particularly with a lightweight, flyable computer. But simple functions of the video signal and deflection voltages, such as the centroid of the observed body of water, will not handle winding rivers, branching rivers, multiple lakes and so forth. Some decision making logic is required to accomplish the task.

A simple approach would be to scan a single line with a color camera. The ratios of the various colors' video outputs would be continuously computed using analog dividers. Comparators would be used to combine the various ratio outputs to derive two logic signals, which would indicate PROBABLE WATER and PROBABLE LAND. A rapid logic state switch in opposite directions in both of these signals would trigger a single-shot multivibrator, latching the camera deflection voltage in a sample-and-hold amplifier. The output of this amplifier would then be a pointing command for the primary imager, and the single-shot output would be the enabling command for picture transmission. Such a system would, however, become confused easily if it encountered winding rivers or rivers running parallel to the scanning line. Further, it would be unable to "backtrack" to follow a bend in the river in the direction opposite from satellite motion.

These problems could be overcome with a technique employing a complete raster scan, but such a system would have to keep track of the previously selected point on the ever-changing picture and incorporate logic to insure that it was really tracking the river rather than jumping all over the picture. Further, the time spent scanning areas of the picture far from the previously selected point represents wasted time and unnecessary complication of the problem.

A technique that would reduce the required hardware, as compared with a raster-scan technique, while providing much better performance, as compared with the line-scan technique, was described in Video Guidance Landing, and Imaging Systems for Space Missions (NASA CR-132746, prepared under Contract No. 1-13558 by Martin Marietta Corporation). This technique is summarized below.

The system would look along a line perpendicular to the path of the satellite for a high contrast edge and determine the orientation of the edge. It would then predict, from knowledge of the edge orientation, where a nearby point on the edge should be found and move to that point. If it found that it was still on the edge, it would center itself on the edge at the new position and find the edge orientation there. The process of predicting and recentering would continue as the detector tracked the edge until the contrast became so low as to indicate that it was no longer viewing a coastline or river, or until the tracking left the detector's field-of-view. It would then return to searching for a new edge.

Coastline Detection Algorithm.- If a television camera scans a circular pattern over a high-contrast edge in an image as shown in Figure 6, the video signal will be, to a first approximation, a periodic square wave of the same frequency as the scanning rate. The scanning is accomplished by adding a voltage $V_x = V_m \sin(\omega t)$ to the vertical deflection voltage, and $V_y = V_m \cos(\omega t)$ to the horizontal deflection voltage, where V_m is much less than the deflection voltage required to cover the width of the sensor field of view.

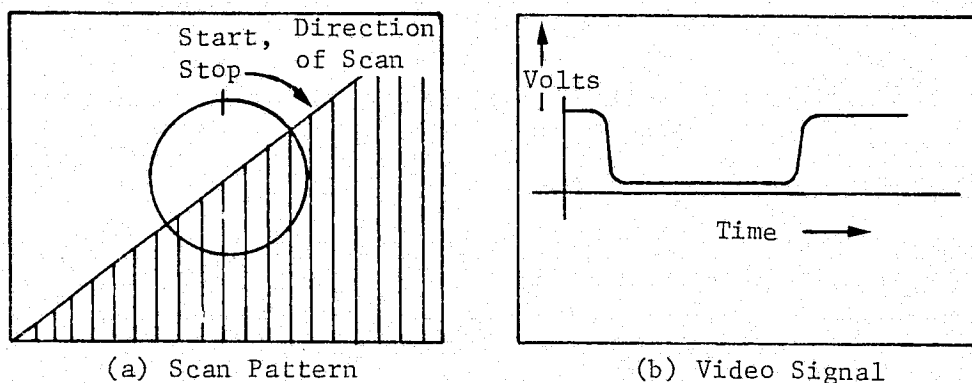


Figure 6.- Scan Configuration

If the fundamental frequency sine and cosine coefficients of the Fourier series expansion of the video signal are interpreted as the horizontal and vertical components of a vector, the vector is found to be perpendicular to the edge and pointing toward the brighter side of the edge. The vector length is greatest for sharp high-contrast edges and has maximum length when the circle is centered on the edge. If the vector length is divided by the video signal dc component, the result is essentially independent of scene brightness.

The required coefficients are readily found with the circuitry in Figure 7, which uses analog computer techniques to compute the Fourier coefficients:

$$a_0 = \frac{\omega}{\pi} \int_0^{2\pi/\omega} f(t) dt$$

$$a_1 = \frac{\omega}{\pi} \int_0^{2\pi/\omega} f(t) \cos(\omega t) dt \quad \text{and}$$

$$b_1 = \frac{\omega}{\pi} \int_0^{2\pi/\omega} f(t) \sin(\omega t) dt, \text{ directly.}$$

The circuitry can be used to seek a coastline by sweeping the center of the circle back and forth across the middle of the image on the camera photocathode at a rate much slower than the circular scanning. If the largest normalized vector length $\sqrt{b_1^2 + a_1^2}/a_0$ is greater than 0.22, a high-contrast sharp discontinuity has been found, and the tracker switches from acquisition mode to tracking mode.

In the tracking mode, the circle is displaced on the photocathode after each decision, starting at the position with maximum normalized vector length as found above. Decisions are made by the following algorithms, which may be implemented with analog or digital electronics or with an onboard computer, if one is provided for other functions. In the algorithm, the "y" direction is assumed to be in the direction of satellite travel, and x_0 and y_0 are voltages to position the scanning. Initially, scanning is positioned at the point determined above. Then the following steps are followed:

- (1) Clear flip-flop A. This flip-flop passes a_1 and b_1 when cleared but multiplies them by -1.0 when it is set;
- (2) Let $\ell = \sqrt{a_1^2 + b_1^2}$ (this can be computed with analog circuitry if this is most convenient in the particular system);
- (3) If a_1 is greater than zero, the system will be tracking in the opposite direction from the satellite's motion,

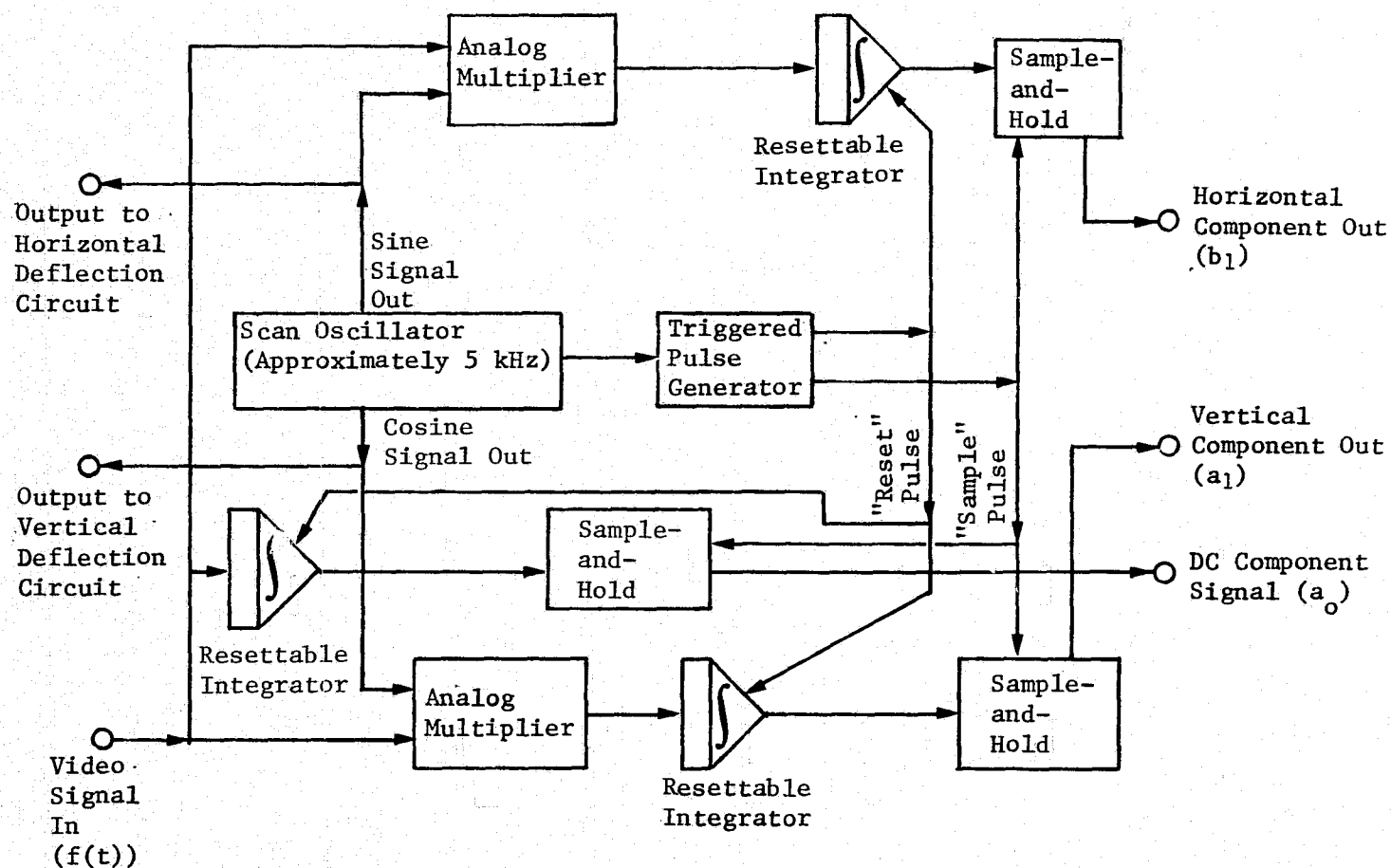


Figure 7.- Circuitry for Computing Vector Components

- (3) (Continued)
so set flip-flop A to reverse the polarity of a_1 and b_1 ;
- (4) Let $y = -a_1 k/\ell$, where k is a gain factor selected for best system performance, chosen during equipment design so that $\sqrt{(\Delta y)^2 + (\Delta x)^2}$ is a fraction of the circle radius;
- (5) Let $\Delta x = -b_1 k/\ell$;
- (6) Let $d_x = \Delta y$;
- (7) Let $d_y = \Delta x$;
- (8) Scan circles centered at $(x_1 = x_0 + d_x + \Delta x, y_1 = y_0 + d_y + \Delta y)$, $(x_2 = x_0 + \Delta x, y_2 = y_0 + \Delta y)$, and $(x_3 = x_0 - d_x + \Delta x, y_3 = y_0 - d_y + \Delta y)$ and determine new Fourier coefficients for each. The centering producing the maximum value of $\sqrt{(a_1')^2 + (b_1')^2}$ is taken as the new (x_0, y_0) , and a_1, b_1, a_0 , and ℓ now become the values for this centering.
- (9) If the procedure has not caused tracking off the photocathode and $\ell/a_0 > 0.22$ go to step (4);
- (10) Otherwise, return to acquisition mode.

Drift in analog circuits can be tolerated if an analog approach is used to implement the algorithm, because the procedure is self-correcting with reasonable drift rates. Correction for satellite motion is required if a very narrow field-of-view is used.

The high-resolution camera is positioned by the tracking camera voltages (x_0 and y_0 in the preceding algorithm). Pictures are taken periodically when the system is in tracking mode. This should produce a high percentage of coastline and river photographs.

Cloud Detection. - A sharp contrasting edge is not necessarily a coastline. The edge might be the boundary between forest and bare rock or soil, between irrigated land and desert,

between cloud and land, or between cloud and water. To be most useful, the algorithm should distinguish between shorelines and other types of edges.

One solution to this problem involves restricting the spectrum the camera "sees" to a part of the spectrum where coastlines tend to produce vectors much longer or much shorter than other edges. Deep red appears to be the best part of the spectrum for this. At 750 nm for example, the reflectance of coniferous forest and granite are very nearly the same, so the "vector" produced by the edge between these two terrain types would be quite short. Water, however, has very little reflectance at this wavelength; and a water-granite or water-forest interface would produce a long vector.

Unfortunately, interfaces between clouds and nearly all terrain types would produce long vectors also. This is shown in Figure 8.

At a single wavelength, a cloud-land interface might produce a vector length very much like that produced by a land-water interface. The confusion can be resolved by computing the vector length again at, say, 470 nm where a land-water edge would produce, typically, a shorter vector--in some cases even opposite in direction--while a cloud-land vector would tend to be near the same length at both wavelengths or actually be longer at the shorter wavelengths. This is illustrated in Figure 9.

Since the algorithm requires that the photocathode be wide but not particularly long in the direction of satellite motion, this two-color measurement might be done with one camera. One half of the photocathode would be used for a scene filtered for 470 nm. The other half would be used for the same image filtered for about 750 nm. This arrangement is illustrated in Figure 10. If a dual aperture image dissector camera were used, the electronics package could simply switch in whichever image was desired or process both in parallel.

A complete description of a tracker of this type is given in the System Design Chapter along with a discussion of the suitability of microprocessors for use in a tracker of this type.

A laboratory experiment was conducted using a simulated cloud and a gelatin filter to verify that the vector length changes in the expected manner with filtering. Experimental

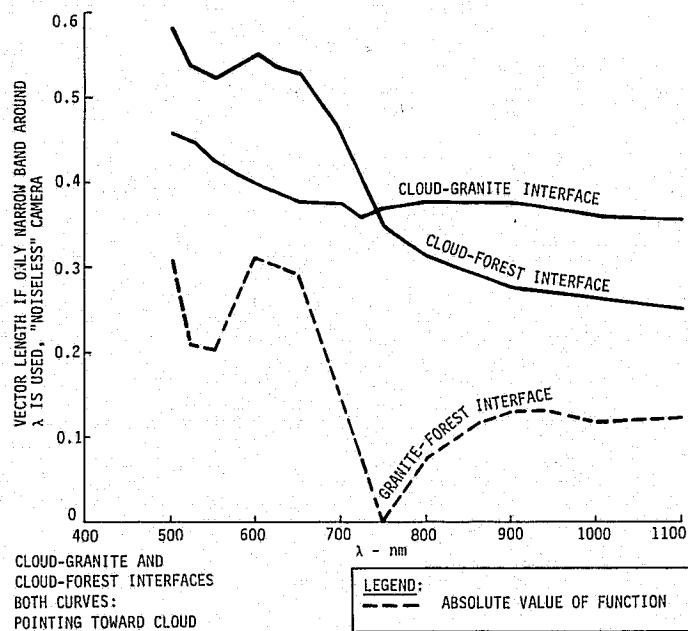


Figure 8.— Vector Length as a Function of Wavelength for Various Interfaces

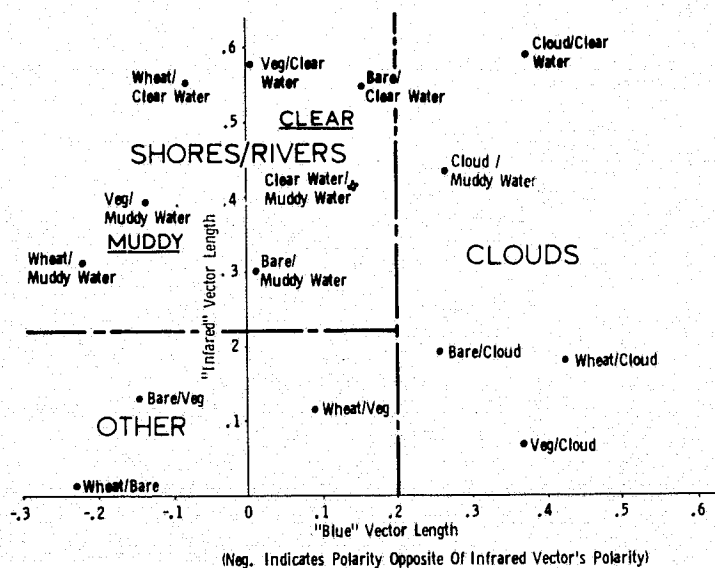


Figure 9.— Blue/Infrared Vector Pairs for Various Interfaces

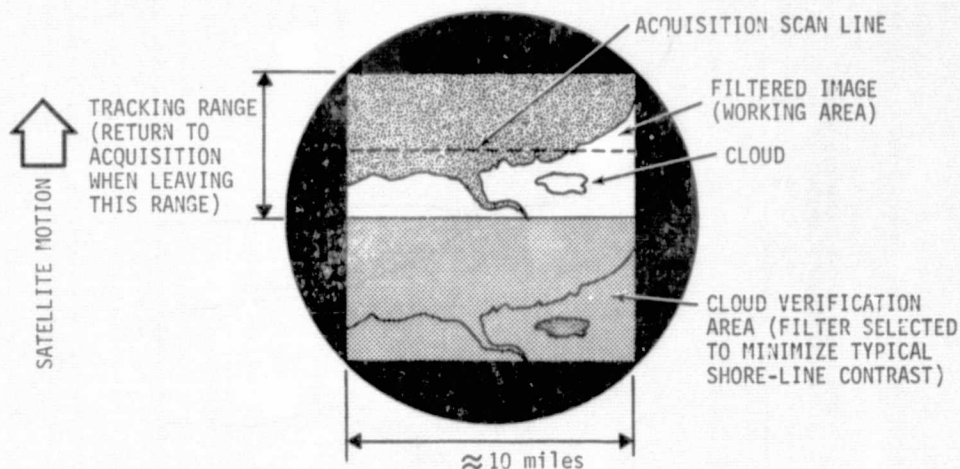


Figure 10- Multispectral Scanning Scheme

results agreed with predicted results, wherein the vector length was changed over a 2.8:1 range by filtering.

The second approach to cloud detection requires more sophisticated electronics but simpler optics. It is based on the fact that, compared to land, clouds and water both tend to appear very smooth at 750 nm. If the electronics package compares the ratio of ac component to dc component in the video signal on the "dark" side of the edge with that on the "bright" side, clouds might be recognized since the bright side in this case has less contrast. This approach shows somewhat less promise than the multifilter approach described shows, but it would be smaller and lighter in weight. Laboratory experiments have not been conducted to test the second method; however, analysis indicates that it would be more apt to make errors than the other method. Good results might be obtained by combining the two techniques.

Experimental Results.- The tracking algorithm has been tested. Figure 11 was produced by a PDP-9 computer from Figure 12 by implementing the algorithm with an image dissector camera and using an analog/digital interface to allow the computer to simulate the functions of some of the electronics. The computer produces a line printer plot of the scene and then, by means of a chart recorder, traces on the plot the path it tracked for a permanent record of the run. The scene used was a satellite photograph as illustrated in Figure 12. To the scale of these images, the "scanning circle" diameter was approximately 6.8 mm (0.27 in.).

Figure 12.-Landsat Image of Chesapeake Bay

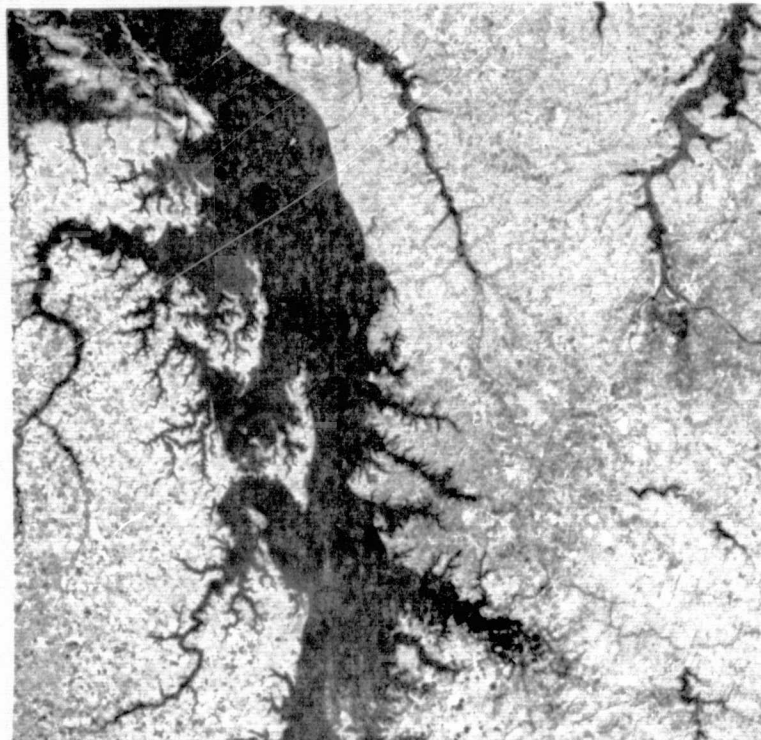


Figure 11.-Record of Track Produced by Algorithm

Figure 11 displays a record of track produced by an algorithm, presented as a dense, multi-line text output. The text is organized into several columns, with each column containing a series of alphanumeric characters. The characters are primarily lowercase letters (a-z) and digits (0-9), interspersed with some special characters like hyphens and parentheses. The overall appearance is that of a raw data dump or a log file, where each line represents a single data point or a step in the algorithm's execution. The text is oriented horizontally, with the columns running from left to right across the page. The density of the characters suggests a high volume of data being processed or recorded.

In this experiment, there were no confusion factors such as clouds or high-contrast features other than coastlines, and no islands were encountered. More experiments were run to see what would happen when these factors were introduced. It was found that clouds over land were not frequently mistaken for coasts. This probably was due largely to chance and to the fact that the clouds were small with respect to the scanning circle. In one experiment, tracking proceeded normally until a coastal cloud was encountered. Tracking then went around the cloud until the satellite motion (simulated by computer software) moved the cloud out of the field-of-view. The algorithm then relocated the coast and continued tracking properly. Similar problems have been encountered with islands. The latter should be a minor problem in a real satellite; however, since the field-of-view changes completely approximately once every 1.2 sec, representing about 9 km (6 mi) of satellite motion. This would automatically prevent continuous encircling of the island. Analysis indicates that the clouds could be avoided by one or both of the cloud detection techniques described earlier.

The minimum vector length for tracking in step 7 of the algorithm on page 31 was determined experimentally. Real coastlines in the pictures used produced vector lengths on the order of 0.25 and few other features produced lengths over 0.10. When the threshold was set to zero, the tracker wandered randomly over the photograph after coming to the end of a river. When the tracker again encountered a coast, it went back to tracking the coast properly. Where picture brightness increased or decreased as a function of distance from the coast, the tracker tended to track a constant-brightness contour parallel to the coast for a considerable distance. The experiment used a threshold of 0.14 to track a feature and 0.03 to cause a return to the acquisition mode. A wide range of threshold settings between 0.03 and 0.25 seem to work well. The optimum setting is difficult to determine using photographs, since it is dependent on what optical filtering is used and perhaps on sun angle and other factors. The maximum length possible is 0.6366.

In conclusion, experiments have been performed indicating that the tracker is capable of distinguishing coasts and rivers from other terrain features and that it would allow the use of lower-resolution cameras for water-pollution imaging and increase the percentage of usable science data returned. This would result in the secondary benefits of lowering the data rate in the radio transmissions to ground and, therefore, potentially lower transmitter power requirements for a given

signal-to-noise ratio. The system could use an onboard computer if one is available, but it is simple enough to be constructed with a reasonably small amount of dedicated electronics.

The technique used for these experiments was a sequential edge-tracking algorithm typically employing an image dissector television camera and a small analog circuit to compute three Fourier coefficients from the video signal. This results in a small logic circuit being able to derive tracking information.

Correlation Techniques

There are many different kinds of correlators, but they all perform the same basic function--matching a reference map with a viewed scene. This may be done simply to recognize when the sensor is viewing a desired scene, to generate an alarm when a scene changes in some way or, most commonly to generate servo error signals to keep the sensor and/or something else pointed at the scene of interest. Generally, a correlator compares the observed scene with one or more reference scenes on a picture-element-by-picture-element basis. The "correlation" is a measure of how well picture elements in the viewed "live" scene match the corresponding picture elements in the stored "reference" scene in relative brightness. To derive a servo error signal, the correlator may try matching the live and reference scenes with various horizontal and vertical offsets, picking the offset with the greatest correlation and generating an error signal based on this offset. Or it may produce a continuous error signal derived from the reference and from the difference in signal amplitude between the live scene and the reference.

The various correlators that have been developed differ from one another primarily in the details of how they do the same basic job. They differ from one another in the type of sensor used; the scanning pattern; the method of alignment; the measure of similarity or "correlation"; the method of storing the reference scene(s); the mechanics of computing the error signal; the operating mode; the portion of the spectrum used; methods for avoiding false lock and contending with mutilations of the scene due to factors such as noise, attitude rate, range closure and clouds; the outputs provided; the amount of human interaction used; resolution and speed, weight and power requirements. This section summarizes what techniques have been used or proposed and how they differ in these respects.

Type of Sensor.— In theory, any sensor that produces an output that is characteristic of two or more points in the observed scene could be used in a correlator. Conceptually, the simplest sensor that has been used in a practical device is simply a non-imaging photocell placed behind a rotating opaque disc containing a slit for light to pass through. The disc mechanically scans the scene, and the output of the photocell is a time-varying current proportional to the scene brightness at the split position. This is illustrated in Figure 13 below.

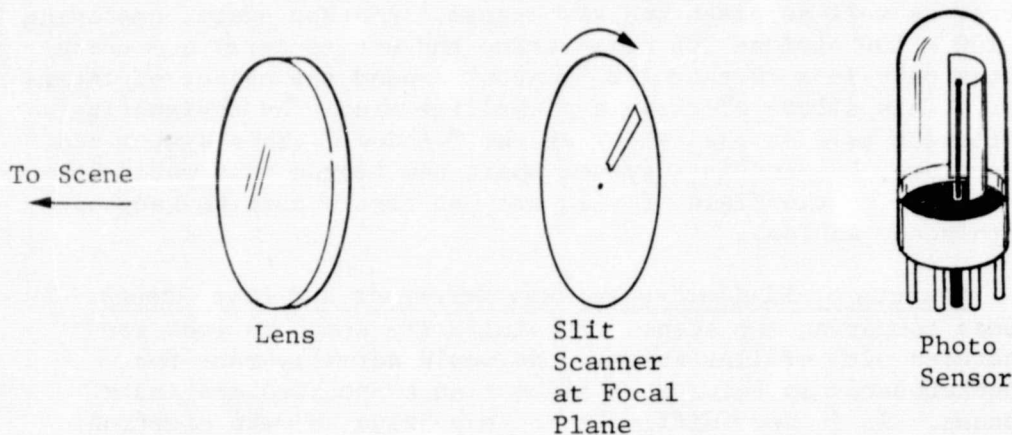


Figure 13.- Slit Scan Sensor Concept

A more modern approach to accomplishing the same thing is to use a linear array of solid-state sensors (CCD, for example) and rotate the array at the focal plane instead of the slit disc. This produces a picture composed of concentric circles, one from each element in the array. Alternately, the array can be swept back and forth like a windshield wiper or nutated back and forth like a push broom. Or several such arrays or single bar-shaped sensors can be arranged like spokes of a wheel and sampled either sequentially or in parallel.

Recently there has been a great deal of interest in using standard television cameras such as vidicons, image dissectors and CCD and CID two-dimensional arrays for sensors. And for day/night operation at short range, radar has been successfully used. An example of the latter is the Modified Azimuth Radar Correlator (MARC) system for missile guidance.

Scan Patterns.- The observed scene is usually scanned, although it is possible to operate on all picture elements simultaneously where a speed requirement justifies the added circuit complexity. The scanning pattern will often be dictated by the nature of the sensor, as in the case of the slit scanner. The pattern may be concentric rings as in the case of MARC, or a standard TV raster scan. One system known as Television Area correlator (TVAC) uses a standard raster scan but uses the video

signal only from four areas at the sides, top and bottom of the picture for correlation. This facilitates determination of soil error as well as pitch and yaw errors. Another system, employing a 100 x 100 element CCD array scans the entire array but correlates only in a rectangular "window" around the object of interest. This allows electronic gimbaling simply by designating a different area on the sensor as the "window." This system can, therefore, be used in a system where the servos that would keep the scene in the field of view are not fast enough to keep up with scene motion.

Measure of Similarity between Reference and Live Scenes.- A human comparing two scenes for similarity tends to look for features with similar shapes. He would normally rate two checkerboards as being more alike than a checkerboard and a banana. It is very difficult and expensive to make electronic circuits respond to shapes. Furthermore, the live and reference scenes are almost always compared on a point-by-point basis. The "score" for scene match is often simply the sum of the "scores" for the individual picture elements making up the scene. The score for each picture element (pixel) is a function of how closely the scene brightness at the point in question matches the brightness of the corresponding point in the reference scene.

Several functions have been used or proposed for comparing picture elements:

- If the peak-to-peak amplitudes of the signals generated by the live and reference scenes are similar, the absolute value of amplitude difference or the square of this difference may be used as a score.
- If the DC component is removed from both signals, the product of the live signal multiplied by the reference signal may be used as a score. This produces true correlation but in some cases is expensive to compute.
- If the signals are thresholded to convert them into two-level logic signals, they may be compared with an exclusive OR gate. If the threshold is properly derived, this technique offers some immunity to small clouds and other small corruptions of the scene, as the amount any one picture element can deduct from the scene correlation "score" is limited. The use of logic signals can also result in circuit simplifications,

particularly if the processing circuitry is to be reduced to a few special LSI integrated circuits.

- Forms of image enhancement, filtering, and rectification and other nonlinear operations may be performed before or after the picture elements are compared. "Scores" for picture elements may be truncated to prevent a few odd points from dominating the score for the picture as a whole.

The score for the scene is generally the sum of the scores for the picture elements. In systems using continuous scanning of the entire field of view and analog signal processing, the summation may be done with an integrator.

In systems producing continuous error signals, the similarity measure itself is rarely generated. Rather, circuitry in the correlator has been designed with a specific measure of similarity in mind, and analysis has been done to insure that the circuitry will indeed track in such a way as to maximize this measure without generating any signal that is proportional to it. This is done using what amounts to a kind of continuous Newton's method of approximating a root. The outputs are servo error signals for orthogonal shift axes and are at each instant proportional to the estimated scene shift required along each axis to minimize the difference between live and reference scenes. In such systems the simplicity of the circuitry used to accomplish this frequently belies the complexity of the theory behind its operation.

In some cases, it may be desirable to normalize the score by using the correlation coefficient:

$$Q(a, \beta) = \frac{\int_X \int_Y R(x, y) \cdot S(x + a, y + \beta) \, dy dx}{\sqrt{\int_X \int_Y R^2(x, y) \, dy dx \cdot \int_X \int_Y S^2(x + a, y + \beta) \, dy dx}},$$

Here R is the reference, S and α and β are the horizontal and vertical offsets. This correlation coefficient makes the score a weaker function of viewing conditions and reference scene content. In other cases, certain picture elements will be weighted more heavily than others.

The selection of the measure of similarity between live and reference scenes to be used in a system depends on many factors, including cost, sensor type, required accuracy and speed, anticipated operating conditions, etc. For example, a system using a digitally scanned sensor may use a digital measure, and a system that must be very lightweight and use little power may use as simple a measure as possible.

With any of these measures of correlation, the scene pair in Figure 14 (a) has maximum possible correlation, (b) has zero correlation, and (c) has maximum negative correlation. These scene pairs illustrate how insensitive correlators are to shapes and scene features that a human would tend to try to match.

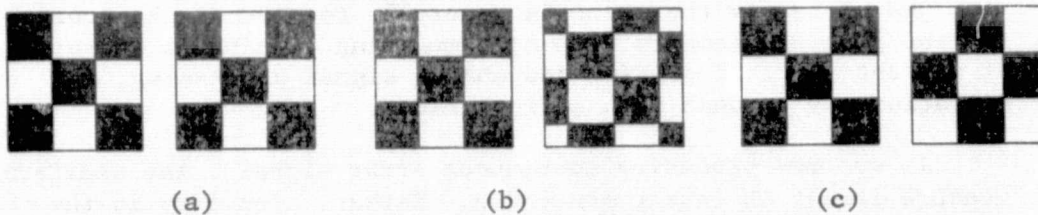


Figure 14.-Scene Pairs

Theoretical work has been done in the last five years to develop correlators that are in some sense optimum. A general correlation analysis appears to be too complex to handle at this time, but solutions have been found for special cases. For example, the problem of determining the maximum-likelihood estimate of the location of the true correlation peak, when the scene is corrupted by gaussian noise, has been worked for the special cases of high and low signal-to-noise ratio and perfect reference scenes in the one-dimensional case (ref 18). Special cases of more readily realizable suboptimal correlators have also been studied. Kalman filter theory has been found to be directly applicable to the design of optimal correlators: and Neyman-Pearson decision theory has been used in a study to determine its applicability to target discrimination.

Recently a two-dimensional transform known as the Walsh-Hadamard transform, a square-wave analog of the Fourier transform, has been proposed as a means of decreasing the storage space requirements for the reference scene. Using this technique, the reference scene could be reconstructed from the stored transform or, it has been suggested, the correlation could be performed in the transform domain. The latter would be a major conceptual departure from the traditional approach. This particular transform is attractive because of the ease with which it can be derived from a video signal and because it generally takes fewer storage elements to store a transformed scene than it takes for the original scene.

This concept uses the Walsh-Hadamard transform matrix to provide a tracker that combines the advantages of both centroid and correlation trackers. In addition, it will track targets of changing shape and contrast in complex backgrounds.

The Walsh-Hadamard transform has been used for many years in image data processing and as a method of reducing the bandwidth that is required for TV transmission. In the Walsh transform tracker concept, some of these techniques have been adapted for use in a tracking system. This tracker departs from the normal raster scan that is the basis for all normal TV systems and most array sensors. The raster scan is a way of sampling the two-dimensional scene data matrix. Other sampling systems are more efficient when the primary use of the image is for an automatic tracker. The transform technique can also be used for displaying the data in a somewhat normal TV display system.

The key feature of this algorithm is that it provides a rudimentary form of image recognition that aids in the tracking function. First step is to sample the scene in the tracking window in a transformed dimension. Figure 15 shows an 8 by 8 section of a TV picture that makes up a tracking window. The Walsh transform technique requires only that n be divisible by 4 with no remainder. The transformation requires that the scene be examined in a two-dimensional matrix. Figure 16 (ref.19) shows the form of this matrix for an 8 by 8 tracking window. As noted, the black areas represent +1, and the white areas are -1. A complete set of terms requires the multiplication of each pattern times the image or scene data.

In a normal array sensor like a charge coupled device (CCD), this transformation can become too complex to perform in real time. However, the charge injection device (CID) that is being offered by General Electric allows the direct sampling of the image in this pattern. If it is desirable to use a CCD, a random access analog memory is available which allows direct conversion from a raster scan format.

Two approaches are currently being studied for the tracking algorithm--(1) the odd terms of the transformed scene are summed to provide a centroid track sense signal. The size of the target is indicated by the even terms. The background can be cancelled by the choice of just a few terms. The result is that $2n + 7$ terms can be used to provide a fully capable tracker. The remaining terms can be discarded or used in other track modes. The result is an area balance tracker that can track at all ranges

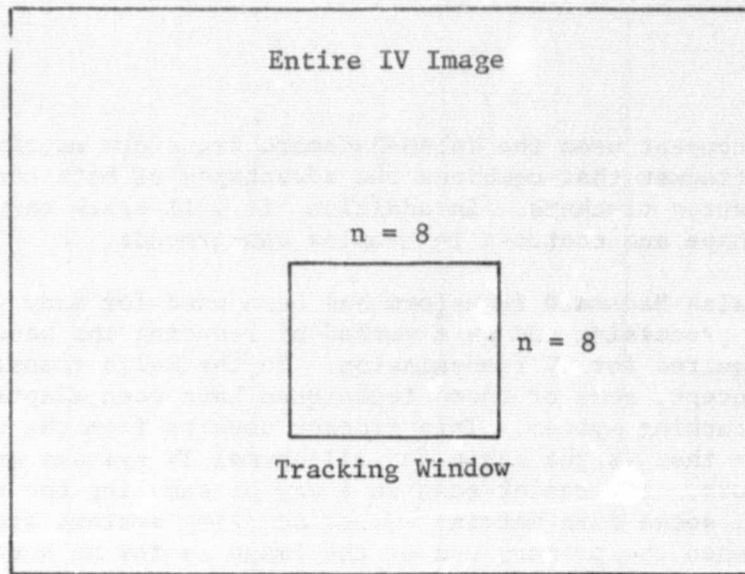
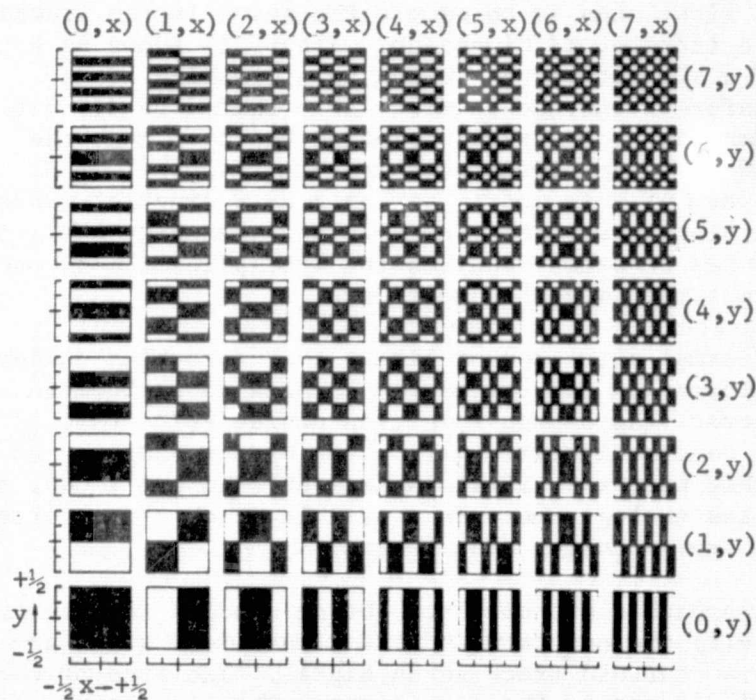


Figure 15.-8 by 8 Tracking Window of TV Picture



Walsh functions, κ, χ and (m, y)
 Black areas represent +1, white areas -1.

Figure 16.-Two-Dimensional Matrix of Target Scene

and with contrast reversal automatically compensated.

In the correlation mode the scene is again transformed as in the centroid tracker. However, a selected number of transform terms are stored in memory. The advantage of this system over older correlators is the reduced storage required, since only a limited number of the terms can be placed in memory. For instance, $(2n - 1)$ storage locations exist instead of n^2 used in some systems.

These two approaches can be readily combined so that the tracker mode selection can be handled automatically. The distribution of the terms of the transform scan can be used to automatically decide whether a centroid tracker is appropriate and allow automatic switching between systems. This would handle the common situation where an aircraft that is rapidly maneuvering might require a combination of trackers to best solve the problem. During the end game the centroid tracker may be limited by the optical field-of-view so that a single tracker might lose lock.

The primary advantage to this system is that it automatically provides a noise cancellation system that will allow tracking at very low contrast levels. The transform inherently improves the tracker signal-to-noise ratio by a factor of $n/2$. Thus, the 8 by 8 window improves the tracking signal-to-noise ratio by a factor of 5. More normal window sizes of 64 by 64 or 128 by 128 provide large improvements in tracking capability.

While the foregoing descriptions use "centroid" and "correlation" to describe the system, they are not accurate since this algorithm provides an entirely new approach to image tracking.

Method of Storing Reference.- A wide variety of media have been used to store reference scenes in correlators. In the slit scan correlator, magnetic drum storage was used, where the drum rotated in synchronization with the slit disc. Advanced and delayed versions of the reference scene were readily picked off with read heads anywhere around the drum. Actual photographic transparencies have also been used successfully in the Modified Azimuth Radar Correlator (MARC), though recently a replacement reference system has been developed for this correlator. Though these mechanical approaches may appear anachronistic in a state-of-the-art device, the concept of drum storage has been retained in more recent designs using recirculating digital shift registers to accomplish the same thing.

More recently, analog shift registers employing CCD technology have come into usage because they promise high-density storage of analog signals.

With the advent of microprocessor technology, semiconductor random-access memories have also come under consideration. Bipolar memories, in general, are fast enough. MOS and CMOS RAMs may have less potential in this area currently due to their relatively long access times. For example, the new MARC reference system mentioned above uses electrically alterable programmable read-only memory (EAPROM) metal nitride oxide semiconductor (MNOS) P-channel technology. Since these devices have access times as long as 1.2 - 1.6 microseconds, a skew storage approach was required in order to use them.

Method of Computation.- The earliest correlators used analog devices such as multipliers, integrators and summing amplifiers to compare the live and reference scenes. Such techniques are still used, but currently digital techniques are receiving more emphasis. The analog multiplier can be replaced by an exclusive-OR gate, the integrator can be replaced by an up/down counter, and analog storage can be replaced by flipflops and registers with a potential saving in weight, cost and power requirements. The digital approach has been found to be particularly attractive when a CCD or CID camera is used, as these devices are by their nature already partly digital.

Microprocessors have also been designed into correlators. For example, at Martin Marietta, a digital reference system has been under development for use with the Modified Azimuth Radar Correlator (MARC) to replace the current photographic reference scene and analog retrieval device. An Intel 3000 series microprocessor system was selected because of its extremely fast cycle time. This microprocessor uses Schottky bipolar technology and bit slice architecture. Even with the high speed of this processor, it was found necessary to use hardware multiplication to meet speed requirements for the system. The less expensive MOS microprocessors currently available have been found to be too slow for all but the least demanding applications, but other bipolar processors are available with cycle times comparable to the Intel 3000 or even faster.

Microprocessors offer the potential of more sophisticated scene matching algorithms. As the cost of these devices and the associated circuitry drops and performance improves, it is to be expected that they will be considered more and more frequently for practical systems.

Operating Mode.— A correlator may be used for a number of different purposes such as tracking a scene once a human operator has pointed the system manually, looking for a scene that matches a prestored image, watching for a change in the observed scene or providing attitude stabilization for a vehicle. The purpose or mode of operation will determine how the reference image is acquired and when, if ever, the reference image will be updated.

One mode is referred to as snap-and-go. In this mode, a human operator manually centers the scene to be tracked in the sensor's field-of-view, typically using a "joystick" to move crosshairs on a television monitor. When the scene is properly set, the operator presses a button. The correlator then memorizes the scene and uses this memorized version as the reference image. This mode might be useful to stabilize satellite instrument pointing once another instrument has located a scene of interest. The second instrument would perform the function of the human operator.

A second commonly used mode is called prestored. As the name implies, in this mode the reference image is stored ahead of time. It may be based on a photograph obtained previously, a map, or an artist's conception of what the scene might look like. This mode might be used for automatic rendezvous and docking, for monitoring of predetermined points on earth or a distant planet, or to guide a vehicle to a preselected landing spot.

In the latter mode, it may be desirable to update the reference scene either by command from earth or from a library of reference scenes kept in some form of bulk storage such as a tape recorder. This would allow a single instrument to monitor a large number of scenes.

In either mode, range closure may require the reference scene to be updated. Typically, this is required each time the distance from the correlator to the object of interest changes more than 20 to 30 percent. Good results have been obtained by having the correlator replace the reference scene with the current live scene every time the correlation "score" drops below a threshold value. In at least one system, outer portions of the field-of-view are updated at a rate different from that used for inner portions since these portions become

obsolete at different rates, and unnecessary updating degrades performance.

A correlator may be used to point at an object that is too small to see, at one that has no characteristics that readily distinguish it from its surroundings, or at one that has characteristics that change or are unpredictable. This is done by using a reference scene that includes surrounding features that are distinct and predictable. If the object of interest does not move with respect to these features, the pointing can be quite accurate. A correlator optimized for this mode of operation is often referred to as an area tracker.

In some cases, the object of interest may be small and moving against a cluttered background. A correlator designed to track such an object is referred to as a point tracker. Such an instrument may use the motion to advantage by subtracting the previous frame's video information from the current frame's information so that a signal is produced only where the two frames differ. Point trackers also may incorporate circuitry to calculate the moving object centroid and logic to reacquire if lock is broken or to point based on the last good information if lock cannot be reestablished. It is advantageous in a point tracker to use only a small portion of the field-of-view at any time and to gate out video information to the correlation logic only for the object of interest. The remainder of the field-of-view is then used for electronic gimbaling by gating a different portion of it to the correlation logic as the object moves.

Portion of Spectrum Used.— Any portion of the electromagnetic spectrum that is capable of providing the required resolution can be used for a correlator. At least in theory, even acoustical waves could be used. Successful operational systems have been built using both RF and optical correlators. Radar systems provide the advantage of day/night operation, but the power requirements for an orbital radar correlator system to monitor the earth would be quite large. Infrared systems have advantages for certain subjects such as vegetation.

Speed and Resolution.— Correlators have been built or proposed with frame rates from one to a few hundred frames per second. Slower correlators have limited application, as the scene must not change greatly while it is being processed.

With a given technology, speed tends to be reduced when

higher resolution is required. This is because the accuracy attainable is typically on the order of two picture elements. To double the pointing accuracy, one doubles the number of picture elements per unit distance in the scene. This results in a sensor with four times as many picture elements per unit area. If the picture elements are compared serially and the same approach is used, we can expect the improved-resolution system to take longer to process the image. But if either the sensor or the object of interest is in motion, less time may be available in a high-resolution system. This is because the image of the scene is more likely to move more than one resolution element on the sensor in the time it takes to process one frame, since the resolution elements have been spaced closer together.

It would also be possible to use a lens of longer focal length to improve the pointing accuracy or to reduce the picture element size to compress the same number of elements in a smaller space. Either solution, however, can result in a requirement for a larger diameter lens. A smaller pull-in range and increased probability of false lock to scenes other than the one desired are also hazards when this is done.

To achieve very high speed and good resolution, one is generally forced to abandon mechanical scanning and use sensors that provide good quantum efficiency and simultaneous outputs from several picture elements. The latter allows the correlator to process different parts of the picture in parallel. CCD arrays have the potential for providing outputs for all the lines in a television image simultaneously at extremely high transfer rates; but to make use of such a sensor, one must make the image bright enough to support such a transfer rate. This generally means using a large lens. Further, parallel processing at high speed is expensive both in the number of components required and in the amount of power required.

Speed and resolution, then, are limited by fundamental constraints of cost, weight, power and sensor quantum efficiency. It does not appear that order-of-magnitude improvements are likely to be made in both speed and resolution in one instrument in the near future. However, current capabilities are more than adequate for a wide variety of tasks.

False Lock Avoidance Techniques.— Not every local correlation maximum between live scene and reference will be a true scene match. For example, if the live scene were a checkerboard and the stored reference were a black square, correlation peaks might be found wherever the reference square lined up with any black square on the checkerboard. Yet, none of these positions represents a good match for the reference. But if perfect correlation is demanded before tracking may begin, acquisition may be prevented altogether by a cloud in the scene, a slight sensor misalignment, an imperfect reference image or sensor noise.

If the correlator is used in snap-and-go mode, initial alignment is guaranteed. The primary requirement for such a system to maintain lock is that it be fast enough to keep from losing lock. However, if the distance to the object of interest is changing or if the object of interest is small and moves over a cluttered background, there is a definite chance of loss of lock anyway. For a correlator operating in prestored mode, false lock may be avoided by using a color camera as a sensor or by keeping the sensor from observing scenes far removed from the desired one by use of ground commands and/or an inertial reference system. The probability of false lock can also be decreased by increasing the number of picture elements.

PRELIMINARY SELECTION RESULTS AND SYSTEM DESIGNS

The baseline system used in the development of a preliminary design is a Waterway Identification and Tracking System (WITS) with a cloud detection capability. This configuration was selected for the following reasons.

- It is applicable to a number of earth observation experiments currently under consideration.
- The technology has been demonstrated in the laboratory.
- It represents a low risk, minimum cost approach to adding a measure of adaptability to a global monitoring mission.
- It is capable of autonomous operation.
- It can be operational in time for Shuttle Orbital Flight Test Missions.
- It has significant growth capability in terms of "learning" potential and correlation growth capability.
- It will provide target identification, selection, acquisition and tracking capability. It can be used for registration of science data.

This chapter summarizes the reference configuration in terms of detailed design parameters which includes the electronics, sensor and optics and provides estimates of weight and power based on actual circuitry. This is followed by a discussion on the relative merits of using a microprocessor in the instrument. The third section of this chapter summarizes the CCD correlator configurations that will require further study for related experiments requiring the correlation function.

Reference Configuration

The Waterway Identification, and Tracking System (WITS) is functionally described in the following section. The primary components are illustrated in Figure 17 and the individual functional blocks are found in Figures 18 through 21.

Functional Hardware.— The waterway acquisition and tracking system receives a "startup" command to initialize it to "acquisition" mode. This signal is held to a logical high state for

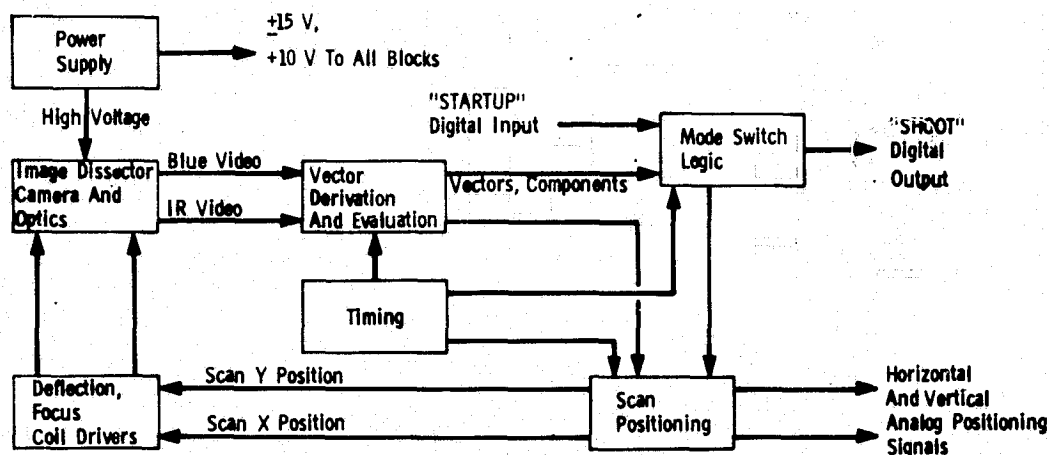


Figure 17.—Waterway Identification and Tracking System (WITS) Block Diagram

at least 100 nsec; it may be held high as long as desired. While this signal is high, the tracker remains in acquisition mode. When it falls to a logical low state, the tracker is enabled to track the next coastline or river it finds.

When a coastline or river is found, the system begins to track it and provides a "shoot" command to turn on any external device. This command is a series of positive-going 5 μ second pulses occurring every 625 μ second and indicating that the analog positioning outputs are pointing to a valid land/water interface.

The analog horizontal and vertical positioning signals may be used to point an external device at the land/water interface being tracked. These signals are present whether the tracker is in acquisition mode or tracking mode and are updated 1600 times per second. The "shoot" command pulses are synchronized to the update rate and may be used to latch the positioning signals if desired.

Vector Derivation and Evaluation.— The blue and infrared

video outputs from the image dissector photomultiplier are amplified by transimpedance amplifiers illustrated in Figure 18. "Blue" and "IR" vectors are produced from these signals, using analog multipliers, integrators and sample-and-hold circuits as described in the previous chapter.

Additional analog signal processing is used to derive a unit-length vector of the same orientation to use in incrementing the scan position. Comparators and logic circuits are used to derive a logic signal, TRACK, which is high if the vector does not represent a coastline. Specifically, TRACK is high if the "blue" vector is too long or if the "IR" vector is too short to indicate a land/water interface.

Comparators and logic circuits are also used to select one of three trial repositionings of the scan circle each time the scan is incremented in tracking mode.

Timing - The sine and cosine waveforms used for the circular scanning are generated using a standard analog computer technique with two integrators and an inverting amplifier. Comparators (Figure 19) detect the zero-crossings of these waveforms to generate sampling pulse (S/H1 - S/H7) that synchronize the operation of the tracker to the scan signals.

Scan Positioning - During acquisition, the scanning circle is swept across the photocathode by using a staircase waveform from an integrator and sample-and-hold circuit. After each circle is scanned, the vector length is compared with the previous "best" vector for that sweep. If it is longer and if the logic signal TRACK (described above) is low, then the vector length is stored as "best" vector and the scan position is stored. At the end of a sweep, then, the "best" vector and its position are stored. If no acceptable vector has been found, the staircase waveform generator is reset and the process repeats. If an acceptable vector is found, the tracker switches to tracking mode. These operations are performed with a comparator, an AND gate, and two sample-and-hold circuits illustrated in Figure 20.

In tracking mode the scanning circle is returned to the "best" position determined in acquisition mode and three circles are scanned: one offset slightly toward land, one offset slightly toward the water, and one with no offset from the "best" position. The vector lengths produced from these three scans are compared to determine the new "best"

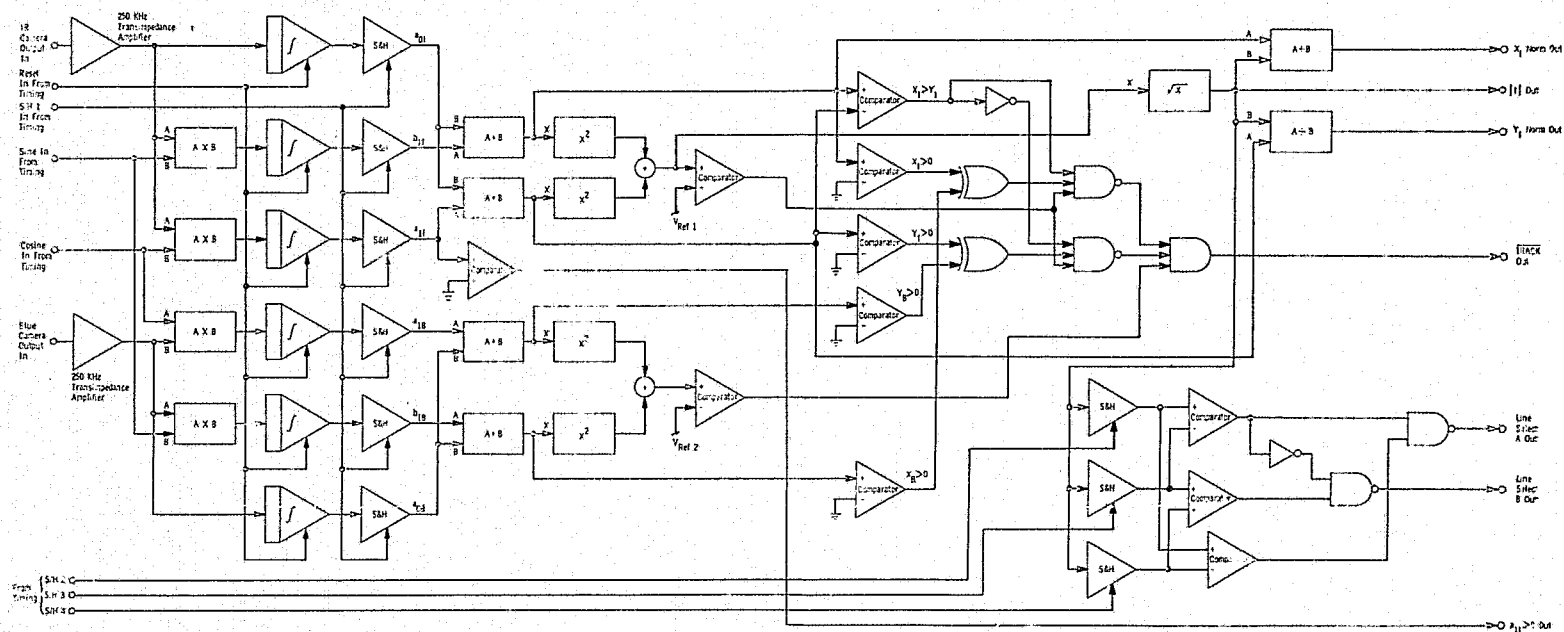
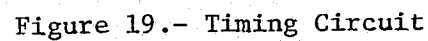


Figure 18.- Vector Derivation And Evaluation



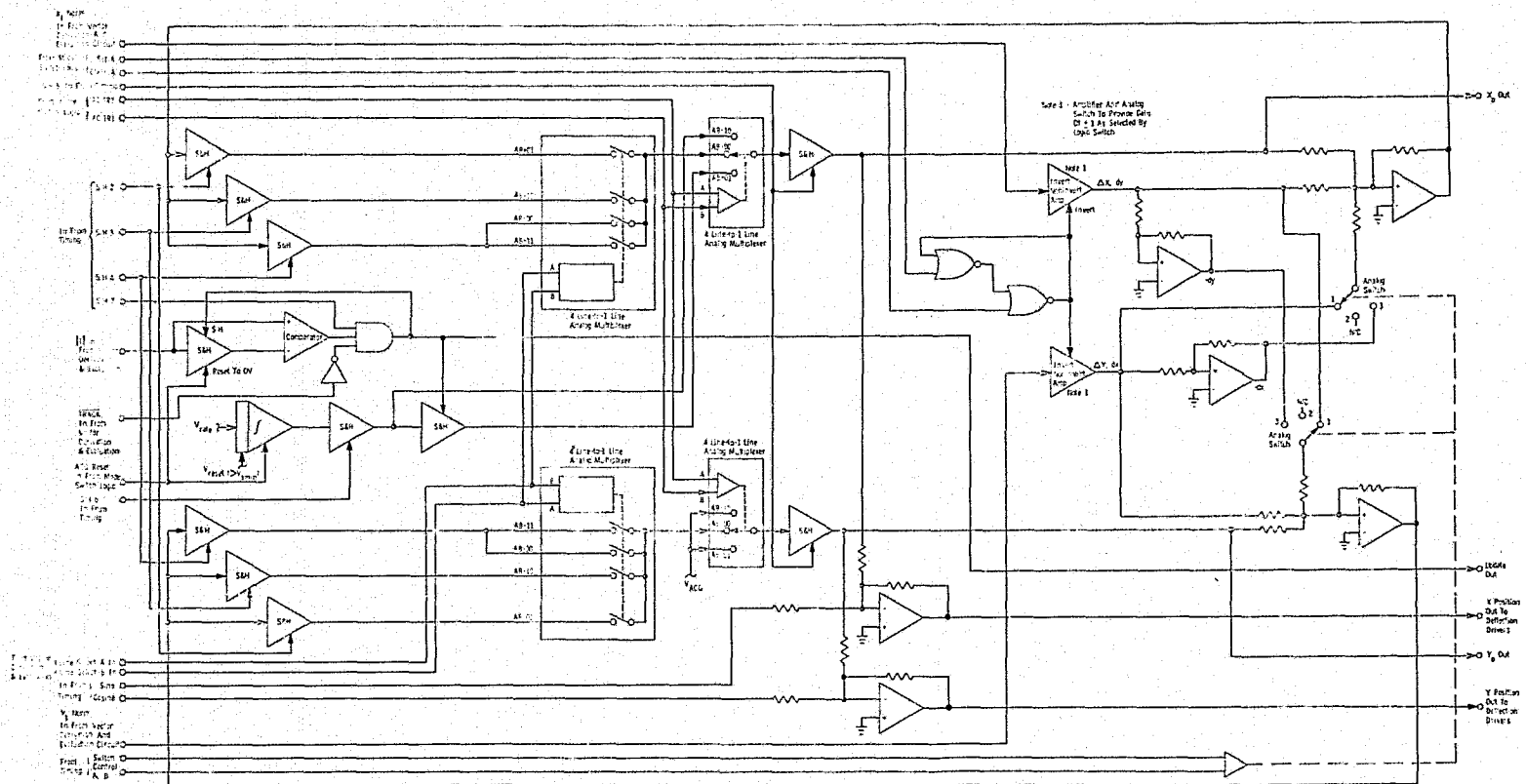


Figure 20.- Scan Positioning Circuit

position, the circle position is incremented along the coastline as described in the previous chapter, and the process is repeated.

During the first iteration in tracking mode, the direction of tracking is checked. If tracking is found to be starting in a direction opposite from satellite motion, the sense of all subsequent vectors will be reversed by invert/noninvert amplifiers.

Mode Switch Logic.- The mode switch logic shown in Figure 21 switches the tracker between acquisition mode and tracking mode. In acquisition mode, when the sweep reaches the edge of the field-of-view, this logic switches to tracking mode. If, however, no acceptable vector has been found, the logic immediately restarts the system in acquisition mode to perform another sweep.

A return from tracking mode to acquisition mode will also result from any of the following:

- 1) At any iteration, the scanning leaves the field-of-view,
- 2) At any iteration, none of the three scanning circles produces a vector indicative of a coastline, or
- 3) The tracker receives a "STARTUP" command from an external device.

Deflection Coil Drivers and Power Supply - The deflection coil drivers are simply voltage-controlled current sources to generate enough current from the scan positioning signals to deflect the scanning in the camera.

The power supply delivers high voltage for the image dissector, +15 volts for the analog circuitry and +10 volts for the CMOS logic circuitry. There is nothing unusual about this supply.

Image Dissector Camera.- For the WITS application, an image dissector was chosen with a (19 mm) S-25 photocathode, two 1-mil-diameter circular apertures and two photomultipliers with gains of approximately 2 million. The camera also contains focusing and deflection coils and optics consisting of a 350 mm f/5.6 lens, image-splitting prisms and filters as illustrated in Figure 22. The rationale for having selected this camera is discussed elsewhere in this section.

Depending on use, it may be desirable to employ an automatic gain control on the camera. This could be done with

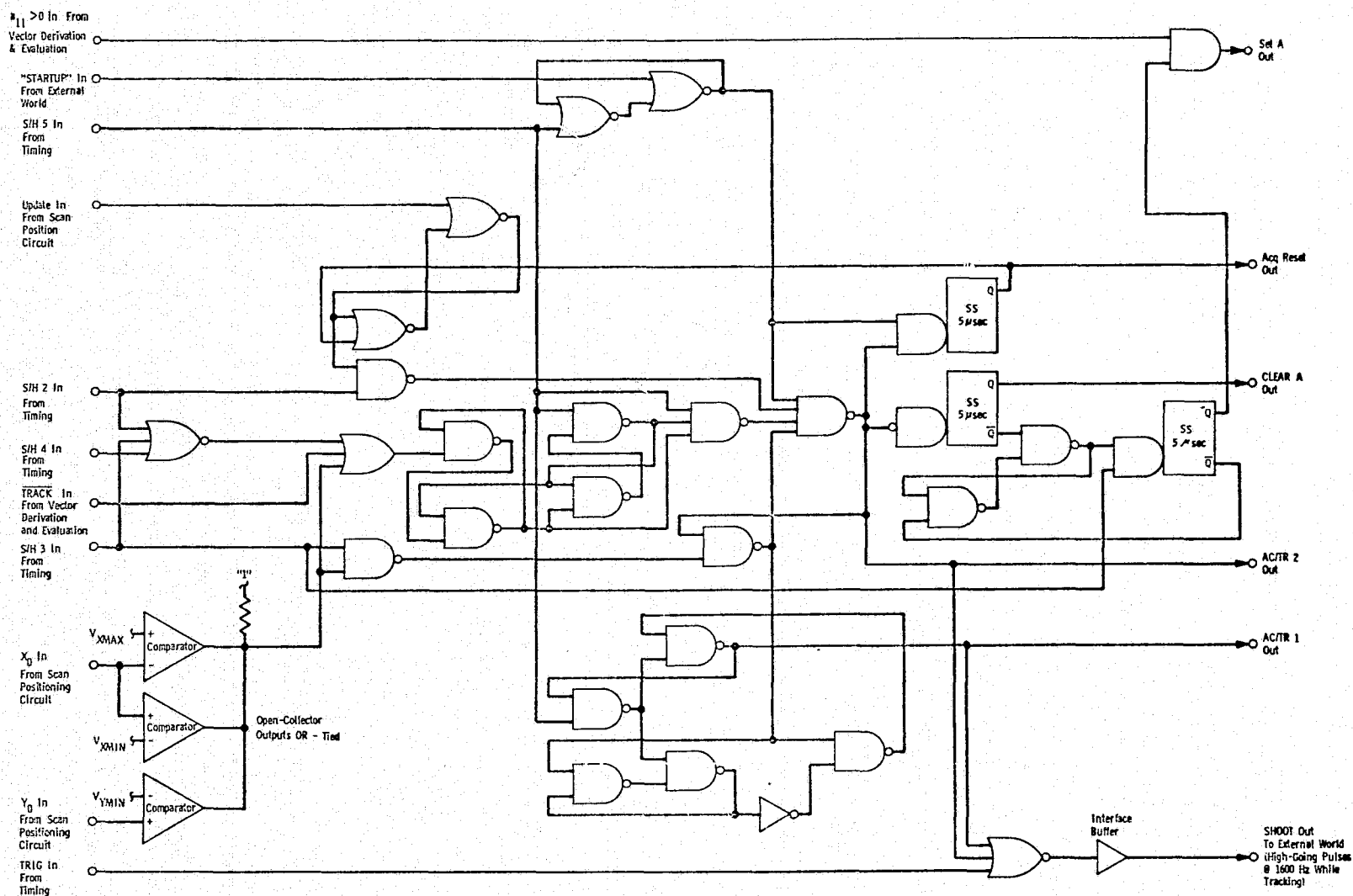


Figure 21.- Mode Switch Logic

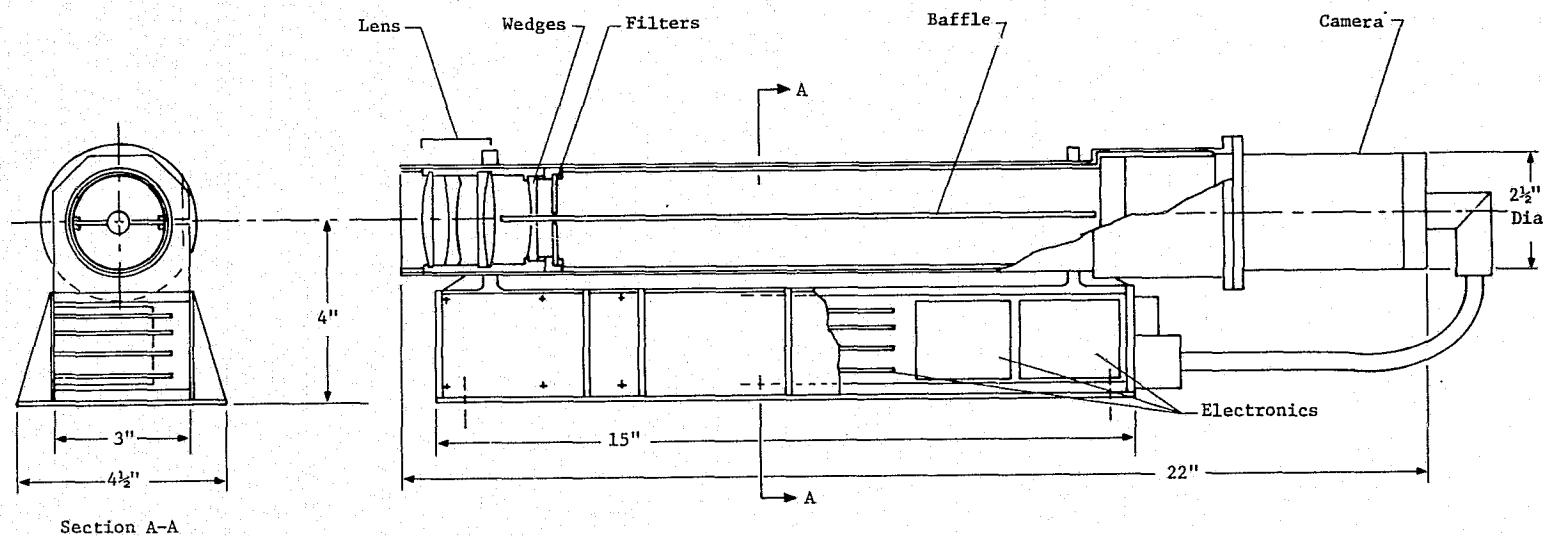


Figure 22.- Waterway Identification and Tracking System

iris control or by controlling the voltage on the photomultiplier. However, the algorithm is self-compensating for a wide variation in scene illumination (several f stops). A gain control would be required if the application were such that amplifiers saturated on one scene while producing so little video signal from another scene that the signal-to-noise ratio became unacceptably low.

Power Requirements and Weight.- The entire instrument requires approximately 28 watts of power at 28 ± 3 Vdc. Of this power, 16 watts are used in the signal processing electronics, two watts are used in the camera, and the remainder is attributed to power conditioning losses.

Weight will depend greatly on environmental and mounting constraints, but 7 kilograms (15 lb) is the estimated weight for a device of this type used aboard an orbiting spacecraft. This weight estimate was based on the mechanical design shown in Figures 22 and 23.

Sensor Selection.- In order to use this approach at all, we must be able to get a voltage or current proportional to the light intensity at points on a small circle arbitrarily placed in the field-of-view. This requirement makes the image dissector camera a prime choice for several reasons. First of all, unlike virtually any other imaging sensor, the image dissector has an output that is proportional to the instantaneous light intensity at an observed spot on the photocathode. Other sensors, such as CCDs, CIDs, vidicons, intensified vidicons and the like, have an output that is proportional to the time integral of the light intensity at the observed point over the interval between observations of the point. This means that the image would have to be erased after each scan by reading out all picture elements in the vicinity of the scanning circle. Alternately, a large portion of the field-of-view could be scanned and the appropriate picture elements could be gated out to derive an effective circular scan. Either approach needlessly slows system operation and significantly adds to system complexity.

The second advantage of the image dissector is that it has a continuous image. Cameras that have advantages for other space applications, such as solid state imagers, have the image divided up electrically into discrete picture elements. This would give a distorted scanning circle at best, and in the case of the CCD or CID, in particular, would greatly complicate the scanning circuitry.

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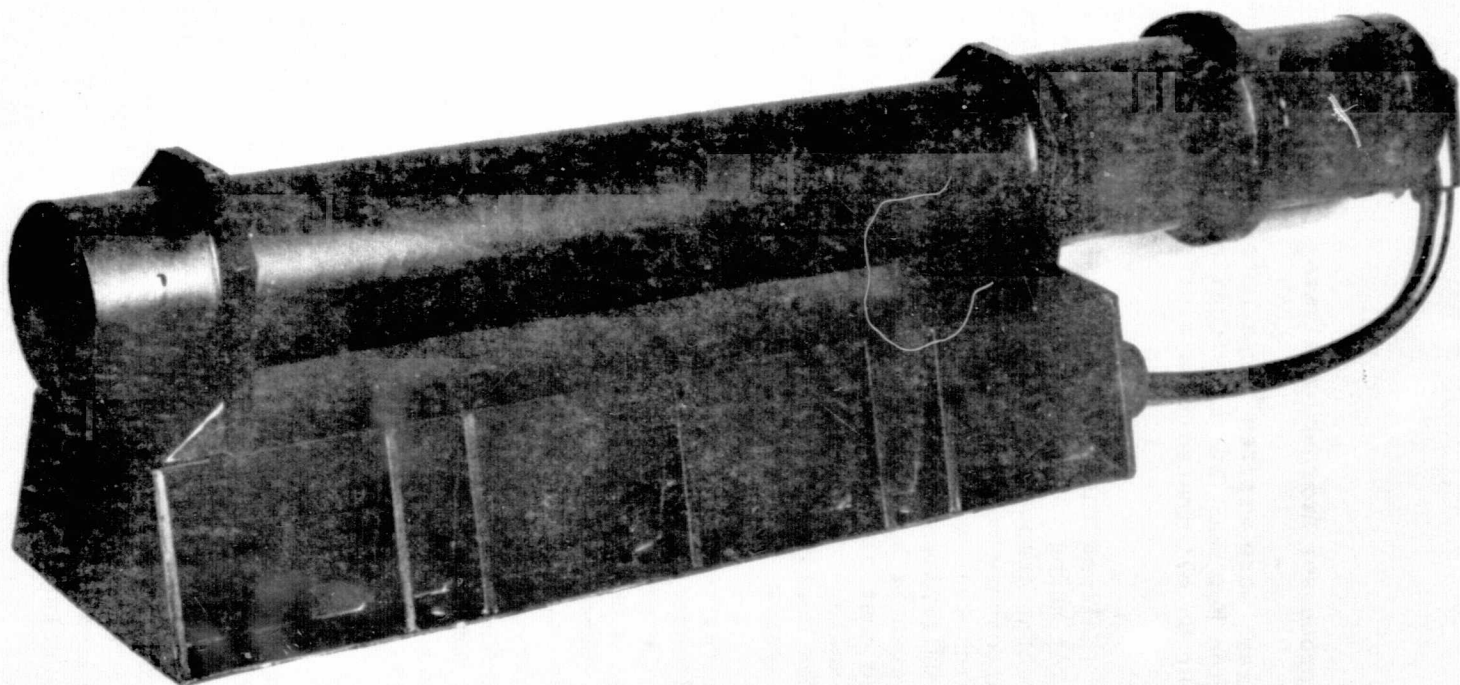


Figure 23.- Waterway Identification and Tracking System Model

Microprocessor Approach Analysis

Benchmark programs were written for a Motorola 6800 microprocessor to determine how much of the signal processing and logic circuitry might be eliminated if a microprocessor were used.

It was quickly realized that no microprocessor could do an adequate job of replacing the signal processing circuitry that produces the vector components. Even a bipolar processor with bit slice architecture would be hard pressed to keep up with the rate at which the ground passes under the satellite because of all the multiplication and division operations. This would be true even if hardware multiplication were used. Also, with the added cost of such a high-performance processor and the high-speed analog-to-digital converters that would be needed, such a system could not currently be built for the cost of the analog system.

It was, therefore, concluded that only the scan positioning, mode switching, and vector evaluation tasks were suitable for a microprocessor. The program shown in Figure 24 was written to determine whether a 6800 microprocessor could perform these functions. It was found that the routine takes about 843 μ sec to execute using the same 5000 Hz scanning rate employed in the discrete logic approach. This compares favorably with the 625 μ sec required without a microprocessor. Memory requirements for such a system would be modest--on the order of 1 kilobyte of read-only memory for program storage and 256 bytes of read/write memory.

Conversely, in order to use a microprocessor, the vector components must be converted to digital form. This means that at least four analog-to-digital converters are needed. Also, at least one digital I/O port must be provided to interface with hardware-derived logic signals. The combined cost of the microprocessor, memory, timing circuits and interface circuits significantly exceeds the cost of the circuitry it could replace. It is, therefore, recommended that a hardwired approach be used unless the flexibility afforded by using a microprocessor is absolutely necessary.

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*ROUTINE 'TRACK' - TO POSITION SCANNING CIRCLE AT
*THREE TRIAL POSITIONS, DETERMINE THE POSITION
*THAT IS CENTERED BEST ON THE LAND/WATER INTER-
*FACE, AND INCREMENT THE POSITIONS SCANNED ALONG
*THE INTERFACE.

*
*'CDN' IS A HARDWARE STATUS WORD SYNCHRONIZED TO
*THE MICROPROCESSOR CLOCK SO THAT IT IS ALWAYS
*VALID WHEN READ.

*
*'VALID' IS A HARDWARE REGISTER SIMILAR TO 'CDN'

```

*
TRACK  LDA A    XDEFL  ADD UP DEFLECTION
      ADD A    DX      COMPONENTS
      BVS     ACQUIS  TO GET
      ADD A    DY      X DEFLECTION TO A.
      BVS     ACQUIS  EXIT IF OUT OF
      STA A    DEFLX   FIELD OF VIEW.
      LDA B    YDEFL  DO SAME
      ADD B    DY      FOR
      BVS     ACQUIS  Y DEFLECTION
      ADD B    DX
      SVS     ACQUIS
      STA B    DEFLY
      PSH A
LP1    LDA A    CDN    SAVE A (=Y DEFLECTION) ON STACK
      BNE     LP1     (ACCESS STARTS SCAN)
      LDA A    ABSVEC  SCAN COMPLETE? IF NOT, LOOP.
                        GET IR VECTOR LENGTH FROM A/D

```

```

      STA A    VMAX
      STA B    XPOS   SAVE IT
      PUL B    XPOS   SAVE X DEFLECTION
      STA B    YPOS   RECOVER Y DEFLECTION FROM
      LDA A    XDEFL  STACK AND SAVE.
      ADD A    DX      GET BASE DEFLECTION
      BVS     ACQUIS  AND REPEAT
      STA A    DEFLX  THE ABOVE PRO-
      LDA B    YDEFL  CEDURE FOR NEW
      ADD B    DY      CIRCLE.
      BVS     ACQUIS
      STA B    DEFLY
      PSH A
LP2    LDA A    CDN
      BNE     LP2
      LDA A    ABSVEC
      CMP A    VMAX
      BLE     SKP1
      STA A    VMAX
      STA B    XPOS
      PUL B
      STA B    YPOS
      LDA A    XDEFL
      ADD A    DX
      BVS     ACQUIS
      SUB A    DY
      BVS     ACQUIS

```

IS THIS VECTOR LONGER?
NO, THEN SKIP.
ELSE RECORD IT AS NEW
MAX. AND RECORD ITS
X/Y COORDINATES
FOR REFERENCE.
GO THROUGH SAME PRO-
CEDURE FOR A
THIRD CIRCLE

```

      STA A    DEFLX
      LDA B    YDEFL
      ADD B    DY
      BVS     ACQUIS
      SUB B    DX
      BVS     ACQUIS
      STA B    DEFLY
      PSH A
LP3    LDA A    CDN
      BNE     LP3
      LDA A    ABSVEC
      CMP A    VMAX
      BLE     SKP2
      STA A    VMAX
      STA B    XPOS
      PUL B
      STA B    YPOS
      LDA A    VALID  WAS AT LEAST ONE VECTOR
      BEQ     ACQUIS  FROM A COASTLINE? IF NO, EXIT
      LDA     XDEL    ELSE RECORD HARDWARE-
      STA A    DX      NORMALIZED VECTOR COM-
      LDA A    YDEL   PONENTS
      STA A    DY      AS NEW DX AND DY
      BRA     TRACK   LOOP BACK TO START OF ROUTINE

```

Figure 24.- Tracking Program for 6800 Microprocessor

Candidate Correlator Systems

Two candidate concepts will now be introduced to illustrate how correlators would be mechanized in a landmark tracking application.

Science instrumentation having a requirement for pointing at a small area on earth for an extended period of time would benefit from this type hardware. The orbital motion of the spacecraft and its attitude limit cycling make it necessary that these instruments be placed on gimballed mounts. High quality gyros are often required to stabilize these mounts. Compensation for the satellite's orbital motion with respect to the monitored point on earth requires even more sophisticated equipment, and since this compensation would, in general, be open loop, the stability is limited. However, a relatively simple correlator could be used in the "snap-and-go" mode to provide closed-loop pointing with high precision without an inertial reference system.

The major considerations affecting the design of this correlator are outlined below:

1. For satellite/spacecraft applications, light weight and low power consumption are important considerations. Solid-state sensors and digital signal processing using CMOS logic would, therefore, be desirable.
2. Relatively high speed operation is required to keep an instrument pointed at a small spot on earth from a moving satellite. This requirement will most easily be met if electronic rather than mechanical scanning is used. Therefore, an imaging (TV type) sensor would be more desirable than most linear array sensor configurations.
3. Range closure and roll about the instrument boresight axis will be second-order effects. The primary outputs required are deflection along the line of satellite/spacecraft motion and deflection perpendicular to this line. These outputs can readily be provided with standard television raster scanning.
4. Since a digital approach is required to scan a CCD array, and since digital signal processing using CMOS and low-power Schottky logic will minimize power

4. (Continued)
requirements, the most natural choice for the measure of scene similarity is a digital one. The video signal from the sensor can be thresholded so that approximately half of the picture elements are quantized as a logic "1" state and the other half are quantized as a logic "0" state. An exclusive-OR gate can then be used to compare the live and reference scenes.
5. No long-term storage of the reference scene is required, as the correlator operates in a snap-and-go mode. The application also guarantees that the system will not initially be locked to a false correlation peak. Elaborate techniques to prevent false lock are, therefore, not required.
6. The portion of the spectrum used for this application is not critical. CCD sensors tend to have good response in the red and near infrared portion of the spectrum. This response will tend to emphasize the contrast between land and water, which is often desirable.
7. As a basis for developing the candidate design, we will assume that this device will operate at an altitude of about 200 km (124 miles), pass over the point of interest at 31,000 km/hr (19,300 mi/hr), and must maintain a pointing accuracy on the order of 100 meters (328 feet) on the ground. Since a correlator of this type can be expected to have an accuracy approximately equal to twice the picture element spacing, these numbers suggest the use of an RCA 320 x 512 element array covering a 51.2 x 32 km (31.8 x 19.9 mi) area on the ground using an 80 mm lens. The exact "f" number required will depend to some extent on the scenes to be monitored, but a minimum usable lens diameter can be found from the resolution requirement:

$$\frac{100 \text{ m}}{200,000 \text{ m}} = \frac{2.44 \lambda}{D}, \text{ where } \lambda = \text{wavelength of response peak in millimeters, and}$$

D = lens diameter in millimeters

7. (Continued)

This equation implies that $f/22$ diffraction-limited optics would marginally meet the resolution requirements. If a frame is to be scanned in the time it takes for the satellite to move one resolution element, the frame rate must be at least 86 frames per second. This high frame rate suggests that a significantly larger lens would be required for typical subjects. For the candidate design, $f/4$ optics will be assumed. The minimum frame rate also implies that picture elements will be clocked out at 17 Megahertz. Though specific information on this array is not available at this clock rate, a CCD 121 linear array, manufactured by Fairchild, has been tested at Martin Marietta and found to perform satisfactorily at 16 Megahertz. CMOS logic may not be fast enough to perform all of the required logic functions at this frame rate.

Based on the above considerations, the following candidate design was developed.

CCD Correlator Design.— Like most correlator/TV trackers presently available, this system uses a small portion of the total field-of-view (FOV) to perform correlation and tracking. However, this correlator allows tracking the point of interest over virtually the entire TV raster without updating the reference scene. The chance of loss of lock to the scene due to satellite motion is thereby minimized, and the problems associated with loss of lock due to rememorization are eliminated.

Upon command from the ground or other spacecraft instruments, the gimbaled mount containing the correlator and the stabilized instrument is pointed at the scene of interest. Video data from the correlator sensor could be transmitted to earth for use in this operation if this were desired. The tracking function is then engaged, and the system automatically tracks the scene of interest. A track command causes the live scene to be stored into a shift register memory. During the racking mode, the contents of this reference memory are correlated with the appropriate portions of successive video fields to produce horizontal and vertical error signals. The details of the algorithms implemented in the correlation process will be discussed later; but briefly, the point correlator performs N parallel correlations on each field of video and determines the best fit correlation in the horizontal

and vertical directions from the center of the memorized scene. If the best fit differs by as little as a one resolution element displacement of the live scene with respect to the memorized reference scene in either direction, an error command is generated that repositions the correlation "window" on the sensor. These error commands are then used to generate servo commands to reposition the mount gimbals in order to keep the centroid of the scene being tracked at the center of the sensor field-of-view.

A window position register contains the binary numbers which locate the position of the center of the correlation window within the TV raster. These binary numbers are logically combined with the binary numbers in the CCD camera digital control logic by window gate logic. This logic gates the proper segment of live video to the shift register memory and to the multichannel correlator bank, synchronizing these two so that the stored information always bears an exact spatial relationship to the live video. Window position correction logic converts the position of the best fit correlation into binary numbers that are either added to or subtracted from the binary numbers in the window position register. The correlation window and the tracking are thereby forced to follow the memorized scene throughout the TV raster.

The algorithms exercised in the correlator system permit the simultaneous computation of at least nine tests for correlation on each resolution cell within the correlation window.

The correlation algorithms take the form of:

$$C_{Vj} = \sum_{x,y} \delta(S_{X,Y+j} \oplus V_{X,Y}) \quad (1)$$

$$C_{Hi} = \sum_{x,y} \delta(S_{X+i,Y} \oplus V_{X,Y}) \quad (2)$$

where:

$S_{M,N}$ = stored video in the mth column and nth row,
thresholded

$V_{M,N}$ = live video in the mth column and nth row,
thresholded

$\delta()$ = a function having a value of 0 if its argument
is a logical 1 and a value of 1 if its argument
is a logical 0 state.

Note that the video signals have been thresholded to convert them to logic signals. The symbol \oplus denotes the exclusive-OR operation.

The implementation of this set of algorithms can be thought of as two similar overlaid image transparencies being sequentially shifted in the X and Y directions with respect to each other until the position in which they seem to match is found. The symbols X and Y in the above equations would then be the number of pixels in the transparencies in the X and Y dimension, and i and j would be equivalent to the number of pixels one transparency was shifted with respect to the other. If one were to actually count the number of pixels which match at each shift position i,j, as transparencies are shifted with respect to each other, it would be at a maximum when the two transparencies seem to match. Thus, in equations (1) and (2), C_{Vj} and C_{Hi} represent the total number of pixels which are alike at each horizontal (H) shift position (i) and for each vertical (V) shift position (j). The value of i and j for which C_{Hi} and C_{Vj} are maximum is then a measure of the initial error or mismatch between the two transparencies.

The actual implementation is very similar to the analogy just described except for one very important feature. The algorithm has been implemented in real-time. In other words, the values of C_{Vj} and C_{Hi} are accumulated as each new value $V_{x,y}$ is received from the TV camera. When the last value of $V_{x,y}$ is received from the camera, these numbers are immediately available and, therefore, the positional error is then known. In this manner very little time is consumed in the correlation process. Since the algorithms are actually performed by comparing the real-time video from the camera with stored or memorized video on a pixel-by-pixel or point-by-point basis, this area correlation technique has been called point correlation.

These correlation algorithms require that the memorized video data $S_{X,Y+j}$ and $S_{X+i,Y}$ be available for all allowed values of j and i as each new bit of video $V_{x,y}$ is provided by the TV camera. The value of $S_{M,N}$ is very easily obtained in a tapped shift register memory. There is a specific shift register tap position for each value of i and j. This means that all values of $S_{M,N}$ are available simultaneously.

In this implementation, the correlator allows both i and j to range from -2 to $+2$. This allows nine parallel correlations for each $V_{x,y}$ in the correlation window. (Diagonal shifts could also be used and might improve performance to some extent, but the number of parallel correlations in this case would be 25, which would significantly increase the complexity of the logic circuitry.)

The correlation window has 64×64 resolution elements, requiring a shift register memory of 4096 bits. The optimum window size is a function of the scenes to be tracked. For some applications, a significant saving in memory might be realized by reducing the window size at the cost of increased probability of loss of lock.

The equations (1) and (2) are implemented by comparing the live and reference video signals at nine different taps along the reference memory shift register. This comparison is performed at each tap using a separate exclusive-OR gate, the output of which gates a clock signal to a separate counter for each tap.

At the end of the TV frame period (the retrace blanking period), the nine counters which have totalled the number of good correlations in each of the nine sampling blocks are examined to determine the counter having the largest number of true correlation counts. This counter's address is then used by the window position logic to determine the direction to shift the correlation window within the TV raster to maintain track. Theoretically, the correlation window is shifted a sufficient amount so that, in the absence of noise, seeker motion, and other perturbations, the correlation on the next field would yield zero position error.

The logic presented has the capability of shifting the correlation window up to two resolution elements in any direction within the TV field period. This limit is imposed by the range of i and j implemented. Other values of i and j can easily be accommodated by changes in the hardware.

The ± 2 resolution element shift capability in one frame time also sets the maximum tracking rate available. The 86 frame per second frame rate was selected with this in mind to allow the device to keep up with satellite motion.

A laboratory version of this tracker has been built at Martin Marietta using a 100 x 100 element CCD array and a 32 x 32 element window. The memory and correlators for this instrument were designed using CMOS integrated circuit logic and require less than 50 milliwatts of power. The faster and larger version described here would, of course, consume more power than this, but the requirements should still be modest for an instrument of this capability.

High Resolution Color Correlator.- The second candidate correlator concept is considerably more complex but does illustrate the limits of today's technology. This system would be capable of providing high-resolution color or false color pictures of 7 km (4.4 mile) diameter areas, with a resolution limit approximately two to four meters (7 to 13 feet) at an altitude of 200 km (124 miles).

The library of reference scenes would be stored on a tape recorder. Initially, the system knows where it is from externally produced data. It loads the reference scene, for the monitored area it will encounter next, into the active reference memory from the tape recorder. An external inertial reference unit points the system in the direction of the monitored scene when the internal clock indicates that the spacecraft should be approaching it. The correlator then recognizes the scene and centers itself on the scene. The correlation with the reference scene is measured and compared with a threshold to determine whether or not the scene has changed significantly, and the live video signal is recorded for later transmission to the ground.

Figure 25 is a block diagram of the system. It should be noted that a high-speed Schottky bipolar microprocessor is used to perform the tasks of correlation and interfacing with the ground commands and the tape recorder. Based on its knowledge of the location of the last scene it found, the microprocessor always knows what reference scene to load next into the active reference memory and approximately how many minutes will pass before the next scene can be acquired. The system can, therefore, operate completely autonomously for extended periods of time.

A microprocessor system has been developed for the Modified Azimuth Radar Correlator (MARC) reference unit. It is expected, based on the design of the MARC unit, that this system will be a multiple processor system employing parallel processing of the outputs from the different sensor elements.

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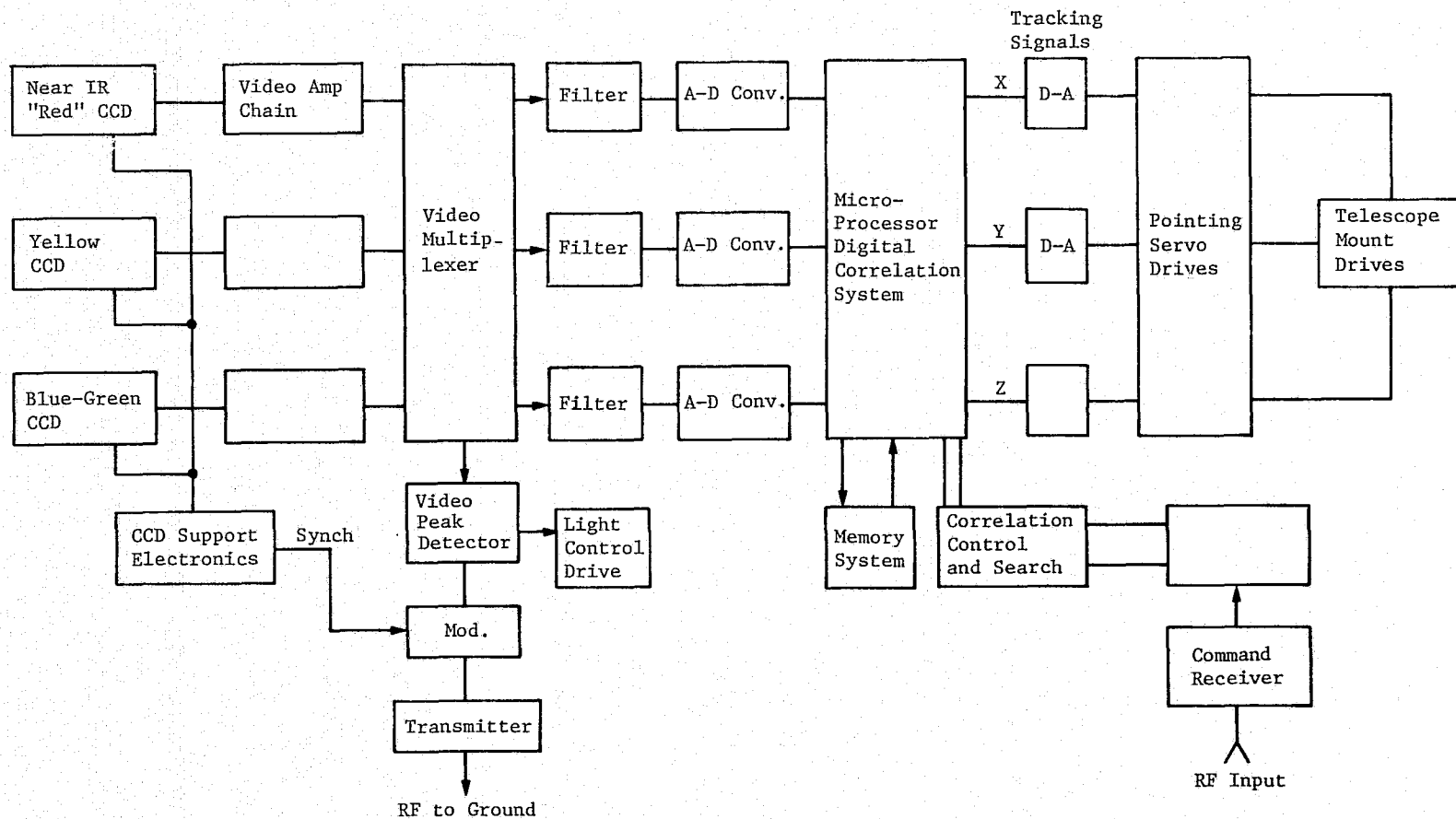


Figure 25.- High Resolution Color Correlator Block Diagram

The lens initially selected for this system is a small telescope such as the Questar type illustrated in Figure 26. Behind the lens a servo-controlled band of neutral density filters controls the amount of light reaching the sensors.

Figure 27 illustrates the sensor configuration. Three 1728-element linear CCD arrays are arranged around a rotating prism that acts as a set of mirrors. The image reflecting off the prism is swept past the three sensors generating three electrical images of the scene. Each image is composed of 1728 concentric circles. A different colored filter is placed in front of each of the sensors so that the three images can be combined to form a three-color photograph of the scene.

The three scenes may be individually correlated with the reference or compared with a color reference by vector subtraction. The servo outputs from the micrporcessor will be continuously updated with each new picture element viewed.

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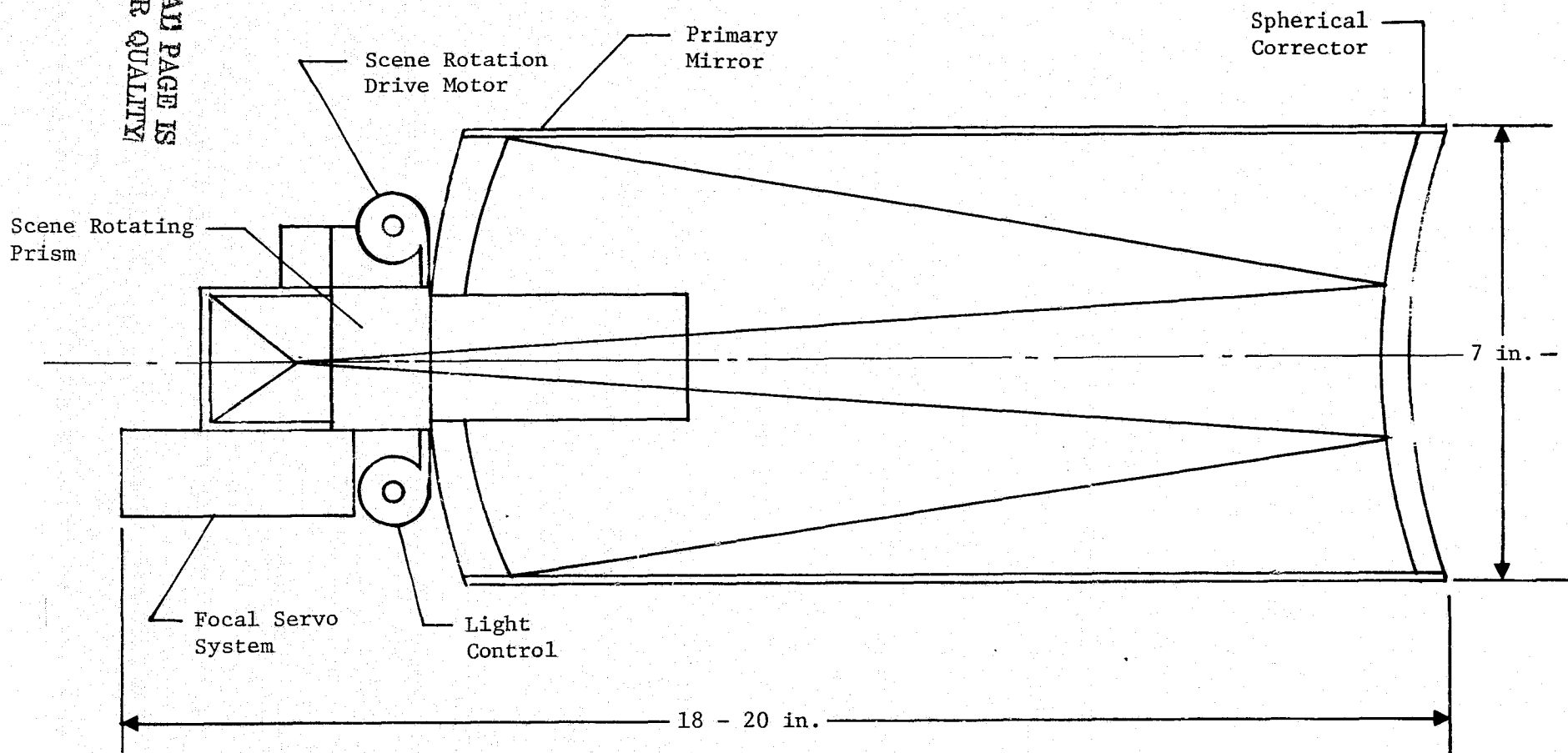


Figure 26.- Preliminary Design Catadioptric Telescope System

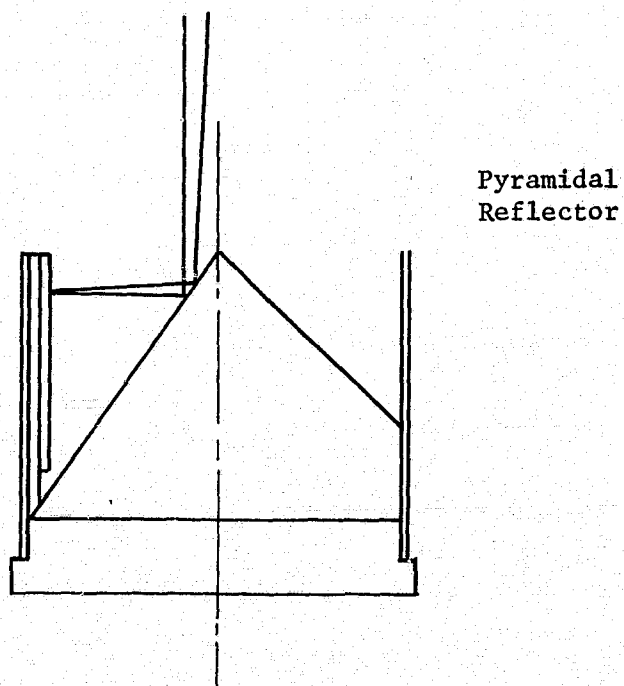
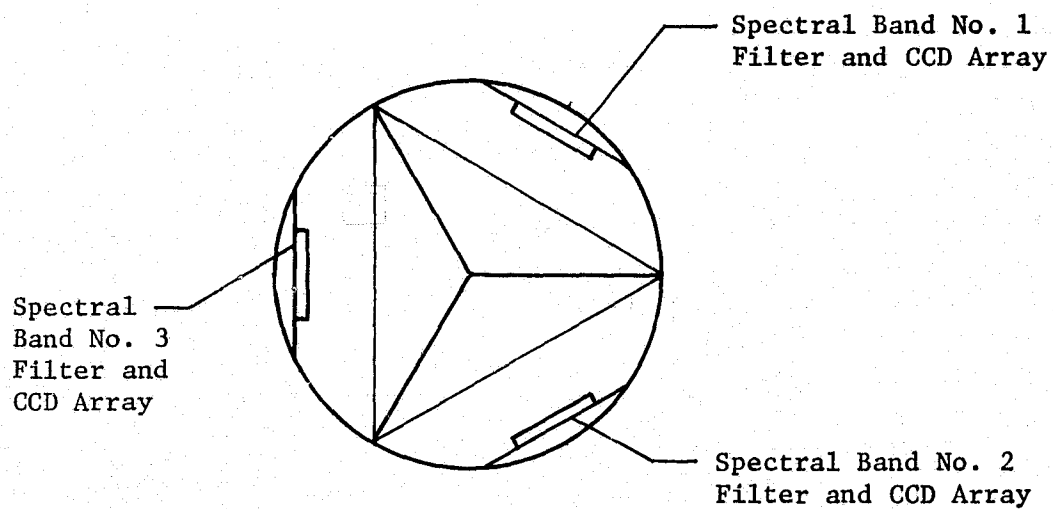


Figure 27.- Focal Plane Design

CONCLUSION

The results of this study indicate that the potential benefits to be derived from the application of adaptive video techniques are as follows:

- Precision landmark tracking for science instrumentation pointing and observation;
- Optimization of science data return with regard to the observable of interest. Acquisition negation of superfluous data thereby substantially reducing data storage, transmission, and eventual reduction.
- Autonomous operation of earth resources science instrumentation via adaptive landmark tracker.
- Target identification, registration, and cloud detection via multi-spectral band ratioing.
- Periodic navigation update via landmark tracking.
- Attitude determination via landmark tracking.
- Target reacquisition during subsequent periodic orbits via image storage and correlation techniques.
- Onboard real-time target discrimination and image enhancement.

This technology will be essential for future earth observation missions to bridge the gap between science data acquisition and storage and eventual postflight data formatting, reduction and analysis. Higher levels of autonomy, adaptive capabilities, and optimized science data acquisition are keynote benefits. Furthermore, the preliminary experiment definition, target spectral analysis, and the design activity have resulted in the following conclusions:

- 1) Spectral band selection and ratioing will enable target identification and tracking.
- 2) The sensor system can be given additional intelligence by providing it with a measure of multispectral ground

- 2) (Continued)
truth with respect to the observable of interest.
- 3) Water quality imaging constitutes a logical initial experiment set for further development and evaluation.
- 4) An experiment pointing mount would provide an ideal platform for evaluation of the imaging system onboard Shuttle.
- 5) The Waterways Identification and Tracking System (WITS) as defined in this report merits further development. Provisions for growth in terms of added intelligence should be provided. This system will weigh 7 kg (15 lb), consume 28 watts of power and occupy a volume of 6000 cm³. Preliminary selection of optics as described in this report will provide a pointing accuracy of better than 60 arc sec with a 2.2 degree field-of-view.
- 6) WITS utility can be increased by adding the correlation function.
- 7) Addition of a microprocessor is not recommended for the design provided.
- 8) Previous experimental results have established the feasibility of the applicable algorithms thereby minimizing the risk.

REFERENCES

1. Schappell, R. T., et. al., "Video Guidance, Landing and Imaging Systems for Space Missions," NASA CR-132746, December, 1975, pp. 65-71.
2. Space Shuttle Earth Observation Sensors Pointing and Stabilization Requirements Study, Report No. 76SDS4228, 7 May 1976. Performed by GE for EVAL.
3. Proceedings of the NASA Earth Resources Survey Symposium, Houston, Texas, June, 1975; NASA TMX-58168.
4. Third Earth Resources Technology Satellite-1 Symposium; NASA SP-351.
5. Target Material Reflectance Characteristics for use with Skylab S-191 Atmospheric Mode; ITEK Technical Report No. 71-8329-10, 24 February 1971.
6. Krinov, E. L., Spectral Reflectance Properties of Natural Formations Technical Translation TT-439, 1953.
7. Gafvert, R. J., Technical Report AFAL-TR-69-124, Exploratory Development of Target Signature Technology, May, 1969.
8. Gafvert, R. J., Lloyd W. Kavanaugh, J., Target Signature Technology Data Compilation-Interim Technical Report No. 1 F33615-68-C-1455, July, 1968.
9. Richards, E. A., Report AD Number 696930, Contrast Enhancement Imaging Devices by Selection of Input Photo Surfaces Spectral Response, September, 1968.
10. Johnson, J., Cooper, K., Bienz, E., Optical Properties of Targets and Background at Night, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia, November, 1965.
11. Orr, D. G., Dwornik, S. E., Yound, L. M., Research Report 1746 RR, AD Number 410588, Reflective Curves of Soils, Rocks, Vegetation and Pavement, April, 1963.
12. Hubbard, R. N., Report AD Number 822402, Consideration for the Application of 254 Nanometer Ultraviolet Photography to Night Aerial Reconnaissance, September, 1967.

REFERENCES - (Continued)

13. Manual of Remote Sensing, Volume I - Theory, Instruments, Techniques, Chapter 13, pages 848-853.
14. Malilu, W. A., et. al., 1971; "Studies of Spectral Discrimination," Report No. NASA CR-WTR-31650-22-T, Contract No. NAS9-9784, NASA JSC and ERIM.
15. Miller, L. D., and Pearson, R. L., 1971, "Aerial Mapping Program of the IBP Grassland Biome," Proceedings of the 7th International Symposium on Remote Sensing, Volume I, University of Michigan, pp. 165-207.
16. Tucker, C. J., 1973, "The Remote Estimation of a Grassland Canopy," MS Thesis, Colorado State University, Fort Collins, Colorado.
17. Maxwell, E. L., 1976, "Multivariate System Analysis of Multispectral Imagery," Photogrammetric Engineering and Remote Sensing, Volume 42, No. 9, pp. 1173-1186.
18. Webber, R. F., "On Optimal and Suboptimal Digital Correlators, Presented at AIAA Guidance and Control Conference, Stanford, CA., August 14-16, 1972.
19. Harmuth, H. F., Transmission of Information by Orthogonal Functions, Second Edition, Springer-Verlag, N. Y., Heidelberg, Berlin, 1972.